KVH® 1775 Inertial Measurement Unit (IMU)

Technical Manual

1775 IMU

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This manual supports all versions of KVH Industries' 1775 Inertial Measurement Unit (IMU). The 1775 IMU is an ultra-compact, extremely precise, commercial strap-down inertial sensor system. It uses three of KVH's advanced proprietary fiber optic gyros that measure angular rate, combined with three low-noise single-axis MEMS accelerometers to measure linear acceleration. The 1775 IMU also includes an integrated three-axis magnetometer that provides magnetic field sensing, compensation, and reporting. The 1775 IMU is ideal for use in high-performance guidance and stabilization applications where low latency, high bandwidth, low- noise, and low bias stability are important parameters. The 1775 IMU is small, lightweight, low-power, and rugged, offering accurate performance in extreme environments. Its flexible digital data and power interface is designed for ease of integration in new applications and upgrades to existing systems.

Technical and performance specifications, interface data, mounting guidelines, and a brief troubleshooting guide are included. For a more complete system overview, refer to **"Appendix C: Electrical Signaling ICD" on page 31**.

KVH Part No.	System Description
01-0363-01	1775 IMU, ±10g accelerometers
01-0363-25	1775 IMU, ±25g accelerometers

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KVH Part # 54-0938 Rev. D

Protected by U.S. patent #6,429,939.

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Product Specifications

Figure 1: 1775 IMU Specifications

Attribute	Value	
Performance: Gyros		
Input Rate	±490°/s max.	
Bias Instability, In-run (constant temp.)	0.05°/hr, 1σ typical 0.1°/hr, 1σ max.	
Bias Offset (room temp.)	±0.50°/hr max.	
Bias Temperature Sensitivity (1°C/minute ramp)	0.7°/hr, 1σ typical 1°/hr, 1σ max.	
Bias Magnetic Sensitivity (up to ±10 Gauss)	±0.5°/hr/Gauss	
Scale Factor Non-Linearity (full rate, 25°C)	≤50 ppm, 1σ	
Scale Factor vs. Temperature (≤1°C/minute ramp)	≤100 ppm, 1σ	
Angle Random Walk (ARW) (room temp.)	≤0.012°/√hr ≤0.7°/hr/√Hz	
Input Axis Misalignment	±0.1 mrad	
Bandwidth (-3 dB)	≥1000 Hz	
Performance: Accelerometers		
	KVH Part No. 01-0363-01	**KVH Part No. 01-0363-25**
Input Limit	±10 g max.	±25 g max.
Bias Repeatability (1 year, full environment)	7.5 mg typical 25 mg max.	3.8 mg typical 18.8 mg max.
Bias Instability, In-run (room temp.)	≤0.05 mg, 1σ	≤0.05 mg, 1σ
Bias Offset (Zero G Bias Level)	±0.5 mg max.	±0.25 mg max.
Bias Temperature Sensitivity (<1°C/minute ramp)	≤0.5 mg, 1σ typical ≤1.0 mg, 1σ max.	0.42 mg, 1σ typical ≤1.25 mg, 1σ max.
Scale Factor Non-Linearity (full rate)	<0.9% max.	<0.5% max
Scale Factor vs. Temperature (≤1°C/minute ramp)	≤100 ppm, 1σ typical ≤500 ppm, 1σ max.	≤250 ppm, 1σ typical ≤500 ppm, 1σ max.

Attribute	Value	
Performance: Accelerometers		
	KVH Part No. 01-0363-01	**KVH Part No. 01-0363-25**
Input Limit	±10 g max.	±25 g max.
Velocity Random Walk (room temp.)	$\leq$0.12 mg/√Hz $\leq$0.23 ft/sec/√h	$\leq$0.007 mg/√Hz $\leq$0.023 ft/sec/√h
Input Axis Misalignment	±1 mrad	±1 mrad
Bandwidth (-3 dB)	$\geq$200 Hz	$\geq$450 Hz
Performance: Magnetometers		
Input Range	±10 Gauss max.	±10 Gauss max.
Bias	<0.2 Gauss	<0.2 Gauss
Noise	<2 mGauss	<2 mGauss
Environment		
Temperature (operating)	-40°C to +75°C (-40°F to +167°F)	-40°C to +75°C (-40°F to +167°F)
Temperature (storage)	-50°C to +85°C (-58°F to +185°F)	-50°C to +85°C (-58°F to +185°F)
Vibration (operating, 30 min/axis)	8 g rms (20-2000 Hz, random) *peak acceleration level limited to 10 g*	15 g rms (20-2000 Hz, random) *peak acceleration level limited to 25 g*
Vibration (non-operating)	12 g rms (20-2000 Hz, random)	12 g rms (20-2000 Hz, random)
Shock (operating)	9 g (11 ms, sawtooth)	25 g (11 ms, sawtooth)
Shock (non-operating)	40 g (11 ms, sawtooth)	40 g (11 ms, sawtooth)
Digital Data Output		
Format	RS422, Asynchronous, full differential	
Data Rate	1 to 5000 Hz, user-selectable	
Baud Rate	9600 to 4147200 baud, user-selectable	
Initialization Time (room temp.)	$\leq$1.5 s (valid data)	
Full Performance Time (room temp.)	$\leq$60 s typical	
Total Motion-to-Output Latency (max. baud and data rates)	$\leq$500 µs	

Attribute	Value
Power Supply	
Input Voltage	9-36 VDC (±5%)
Input Power	5 W typical, 8 W max.
Package	
Weight	1.5 lbs (0.7 kg)
Dimensions	Ø3.5" x 2.9" h (88.9 mm x 73.7 mm)

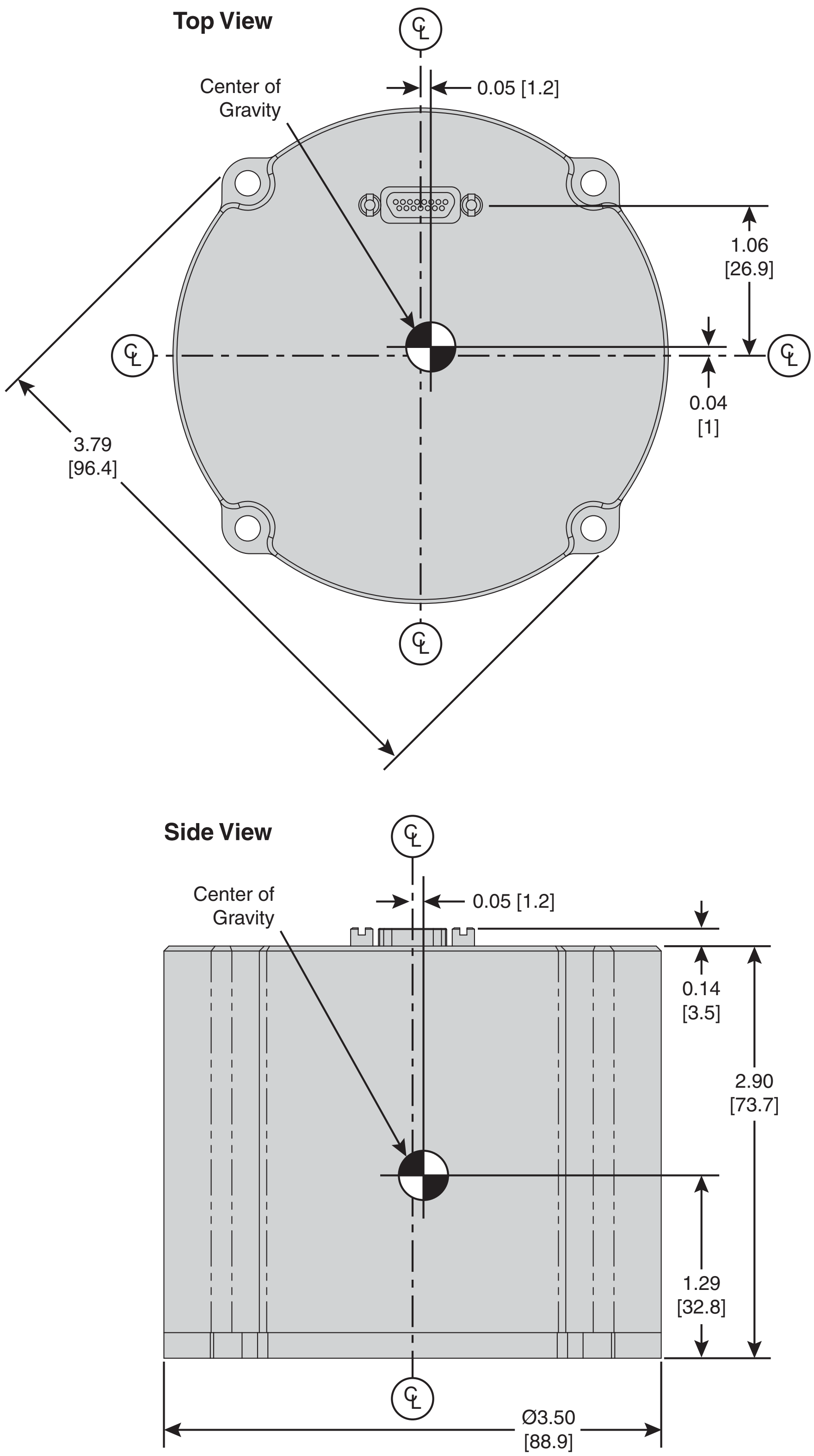
IMPORTANT!

The 1775 IMU is a precision instrument. Handle the unit with care and avoid exposing it to severe mechanical shock.

General dimensions are provided below.

NOTE: *All dimensions are shown in inches [millimeters] format.*

Figure 2: General Dimensions



Storage and Handling

The 1775 IMU may be stored in a location with an environmental temperature between -58°F to +185°F (-50°C to +85°C). Ideally, the unit should be stored at a room temperature of approximately 70°F (21°C).

IMPORTANT!

The 1775 IMU is a precision instrument. Handle the unit with care and avoid exposing it to severe mechanical shock.

The 1775 IMU is a sensitive measuring device. Take normal safety precautions when handling to ensure the integrity of the device. During unpacking and installation, proper ESD handling procedures should be enforced.

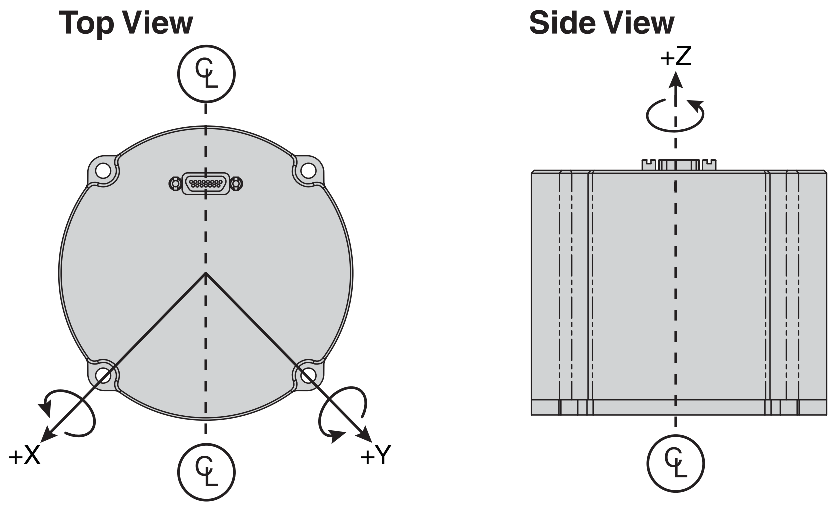
Maintenance

The 1775 IMU is supplied as a sealed unit; there are no field maintainable components. Opening the enclosure will void the warranty and may violate the contract under which the unit was supplied.

Output Orientation

The 1775 IMU senses acceleration and angular velocity on three physical axes, as shown in Figure 3 and Figure 4. You may configure a rotation matrix to set the output axes relative to the physical orientation of these measurement axes, allowing the IMU to measure motion in three arbitrarily orthogonal axes (see “Configuration Options” on page 14). These settings are saved and reapplied on restart. You may revert to the factory default settings at any time (see “Resetting Parameters to Factory Defaults” on page 16).

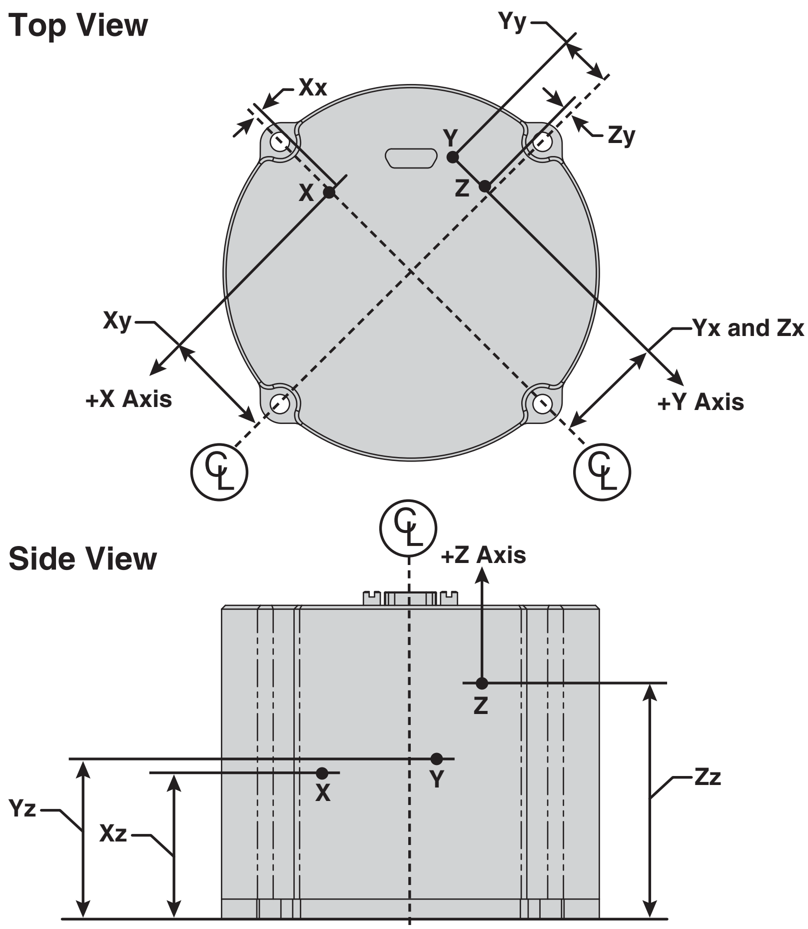
Figure 3: Gyro Measurement Axes Orientation



NOTE: *The three axes of rotation are coincident with the linear acceleration axes. Positive rotation is a counterclockwise rotation about an axis when viewed from +∞ along that axis. Linear acceleration polarity is such that the IMU will report +1 G due to Earth gravity when its + axis is up. The rotation matrix only applies to gyro and accelerometer data. Magnetic data in output Format C is not affected.*

Figure 4 below shows the general physical location of the accelerometer axes and the location of the sensing point on each axis. Figure 5 describes the **specific** location of the accelerometer axes in Figure 4 for each 1775 IMU variant.

Figure 4: Accelerometer Axes and Sensing Points



NOTE: *All dimensions are shown in inches (millimeters) format.*

Figure 5: Location of Accelerometer Proof Mass Coordinates

Coordinate	KVH Part No. 01-0363-01	KVH Part No. 01-0363-25
Xx	0.02 (0.5)	-0.04 (-1.0)
Xy	-1.03 (-26.2)	-1.03 (-26.2)
Xz	1.32 (33.5)	1.32 (33.5)
Yx	-1.01 (-25.6)	-1.01 (-25.6)
Yy	-0.46 (-11.7)	-0.51 (-13.0)
Yz	1.46 (37.1)	1.46 (37.1)
Zx	-1.01 (-25.7)	-1.01 (-25.7)
Zy	-0.02 (-0.5)	-0.02 (-0.5)
Zz	1.77 (45.0)	1.77 (45.0)

Interface Connector

The 1775 IMU is equipped with a 15-pin (male) Micro-D interface connector of the following type: MIL-DTL-83513. Figure 6 shows the connector location. Figure 7 describes the function of each pin. For more information, refer to “Appendix C: Electrical Signaling ICD” on page 31.

Figure 6: Interface Connector Location

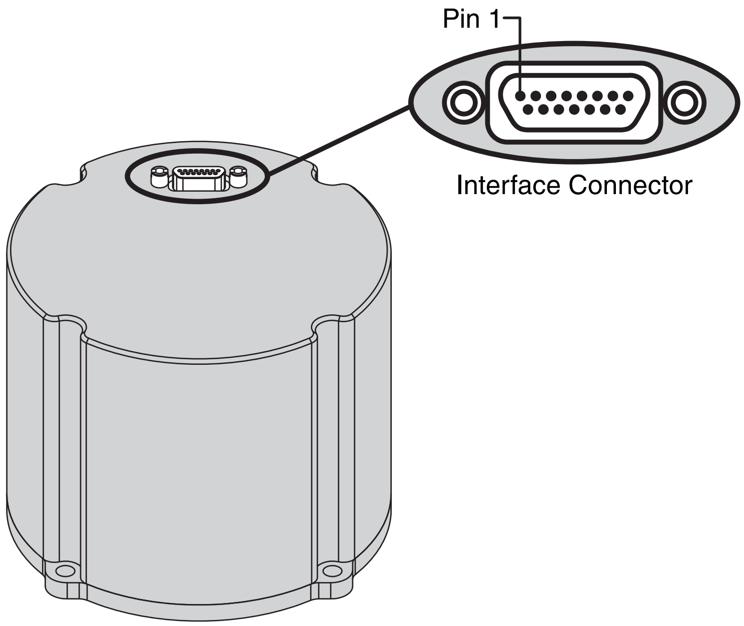


Figure 7: Interface Connector Pins

Pin	Type	Description
1	RS422-TX (+)	IMU RS422 Transmit High
2	RS422-TX (–)	IMU RS422 Transmit Low
3	RS422-RX (–)	IMU RS422 Receive Low
4	RS422-RX (+)	IMU RS422 Receive High
5	EXT-RST (–)	IMU Reset Low (Optional)
6	Config-RST-In (–)	IMU Configuration Reset Low (Optional)
7	MSync (–)	Master Sync Low (External Clock) (Optional)
8	TOV-Out (–)	Time of Validity Signal Low (Optional)
9	Power (–)	Power Return
10	Power (+)	9-36 VDC Power

Pin	Type	Description
11	MSync (+)	Master Sync High (External Clock) (Optional)
12	TOV-Out (+)	Time of Validity Signal High (Optional)
13	Config-RST-In (+)	IMU Configuration Reset High (Optional)
14	EXT-RST (+)	IMU Reset High (Optional)
15	Signal-GND	Do Not Connect

Interface Cable

The power and data interface cable must be fitted with a 15-socket (female) Micro-D connector per MIL-DTL-83513 with a Flourosilicone interfacial seal. You can purchase a 24" (60 cm) shielded interface cable with this connector from KVH (KVH part no. 32-1293-02).

If your application requires a serial cable or interface adapter (such as an RS422-USB serial adapter), make sure it is compatible with the IMU and supports speeds of at least 4 Mbps baud (KVH recommends USB converter Startech ICUSB422 or equivalent set at RS-422, no echo, no term). Also be sure to use shielded cables to prevent signal loss and noise interference.

Data Communications Equipment

A computer or other data communications device is necessary to communicate with the IMU. This equipment's serial port communications must match the IMU’s serial port settings for proper operation.

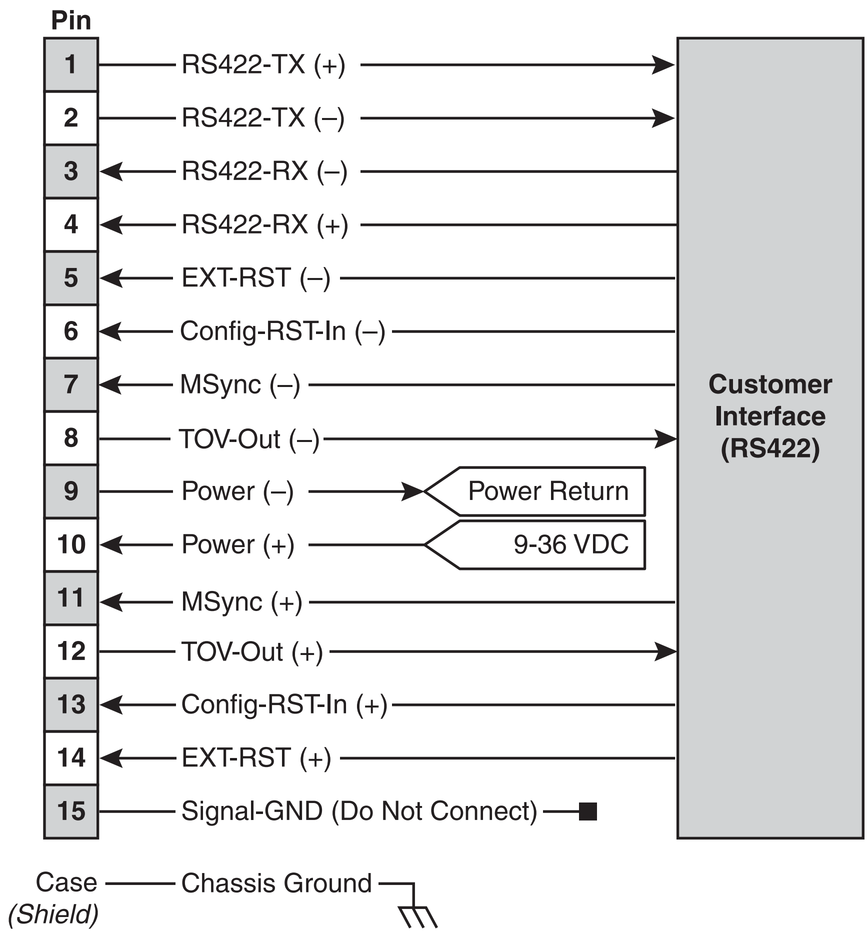
When connected to the IMU, you can enter commands directly from the terminal or through a terminal emulation application.

Use RS-422 differential signaling methods for all 1775 IMU digital control signals (KVH preferred). Alternatively, RS-422 single-ended signaling may be used if cabling susceptibility and other environmental interferences are proven acceptable. For more information, refer to “Appendix C: Electrical Signaling ICD” on page 31.

Wiring the IMU

Use Figure 8 as a guide to connect the IMU to your application. For more information, refer to “Appendix C: Electrical Signaling ICD” on page 31.

Figure 8: Wiring Diagram



Digital Data Output

The IMU provides a digital interface with the following characteristics:

Figure 9: Interface Characteristics

Parameter	Value
Type	RS422
Baud Rate	Selectable: 9600, 19200, 38400, 57600, 115200, 460800, 576000, 921600 (default), 4147200
Parity	None
Start Bits	1 (space, binary 0)
Data Bits	8 (1 message byte, starting with LSB)
Stop Bits	1 (mark, binary 1)
Flow Control	None

An idle line is always marking (in a binary 1 state). Thirty-six (36) characters in sequence constitute a basic message with default settings. For more information, refer to “Appendix C: Electrical Signaling ICD” on page 31.

NOTE: *The IMU’s RS422 RX signals are internally terminated to a nominal impedance of 100Ω.*

Data Output Signal Processing

For information about data output signal processing, refer to “Appendix C: Electrical Signaling ICD” on page 31.

Message Structure

The IMU outputs data in three selectable formats (A, B, and C). Figure 10 and Figure 11 provide an example of message A (default) format and data. Refer to “Appendix C: Electrical Signaling ICD” on page 31 for more information.

Figure 10: Example Message Format (Format A)

Function	Total # Bytes	Description
Header	4	Always 0xFE81FF55; this value will never occur anywhere else
Message data	Varies	Refer to “Appendix C: Electrical Signaling ICD” on page 31.
CRC	4	See Figure 13 on page 13

Figure 11: Example Message Data Format (Format A)

Datum	Byte Number(s)	Data Type*	Units	Notes
X rotational data	5,6,7,8	SPFP	Radians or degrees, selectable	MSB (Byte 5) is output first; delta angle, rate of rotation, selectable
Y rotational data	9,10,11,12	SPFP	Radians or degrees, selectable	MSB (Byte 9) is output first; delta angle, rate of rotation, selectable
Z rotational data	13,14,15,16	SPFP	Radians or degrees, selectable	MSB (Byte 13) is output first; delta angle, rate of rotation, selectable
X acceleration	17,18,19,20	SPFP	g	MSB (Byte 17) is output first
Y acceleration	21,22,23,24	SPFP	g	MSB (Byte 21) is output first
Z acceleration	25,26,27,28	SPFP	g	MSB (Byte 25) is output first
Status	29	DISC	1 = valid data 0 = invalid data	See Figure 12 on page 13
Sequence number	30	UINT8	0-127	Increments for each message and resets to 0 after 127
Temperature	31,32	INT16	°C, 1/100 °C, °F, 1/100 °F, selectable	

* *SPFP = Single Precision Floating Point (IEEE-754); DISC = Discrete Data; UINT8 = Unsigned 8-bit integer; INT16 = Signed 16-bit integer*

Figure 12: Status Byte Format

Function	Bit #	Notes
Gyro X status	0 (LSB)	1 = Valid data, 0 = Invalid data
Gyro Y status	1	1 = Valid data, 0 = Invalid data
Gyro Z status	2	1 = Valid data, 0 = Invalid data
Reserved	3	Always 0
Accelerometer X status	4	1 = Valid data, 0 = Invalid data
Accelerometer Y status	5	1 = Valid data, 0 = Invalid data
Accelerometer Z status	6	1 = Valid data, 0 = Invalid data
Reserved	7	Always 0

NOTE: *In addition to this general status information, an extended built-in test (BIT) may be initiated by entering the "**?bit**" or "?bit,2" command. (Extended BIT data is also output whenever the IMU is first powered on.) The extended BIT provides six bytes of diagnostic data. The 1775 IMU records and reports stored BIT history as an optional diagnostic aid. For more information, refer to "Appendix C: Electrical Signaling ICD" on page 31.*

Figure 13: CRC Format

Parameter	Value
Width	32
Poly	0x04C11DB7
Reflect In	False
XOR In	0xFFFFFFFF
Reflect Out	False
XOR Out	0

NOTE: *The 32-bit CRC used for message data verification ensures the data received (or transmitted) is valid.*

Configuration Options

The 1775 IMU offers more user configurable parameters than the KVH 1725 or 1750 IMU. These parameters can optimize the 1775 IMU performance for specific application need (e.g., faster update rates for higher dynamic conditions, very low latency sensing and time synchronization, digital signal processing filters, and options for ease of platform installation and interfacing to control systems). In addition to the default and standard user options available, customized digital filters are also supported. Figure 14 lists the User-Configuration options. For more information, refer to “Appendix C: Electrical Signaling ICD” on page 31.

Figure 14: User-Configurable Parameters

Parameter	Command	Options	Default
Baud Rate	=BAUD,<*x*>	9600 460800 19200 576000 38400 921600 57600 4147200 115200	921600
Data Rate (Hz)	=DR,<*x*>	1 250 5 500 10 750 25 1000 50 3600 100 5000	1000
Temperature Units	=TEMPUNITS,<*x*>	C F C_100 *(1/100 expanded resolution)* F_100 *(1/100 expanded resolution)*	C
Angular Units	=ROTUNITS,<*x*>	DEG RAD RESET	RAD
Angular (Gyro) Data Format	=ROTFMT,<*x*>	DELTA *(radians or degrees)* RATE *(radians or degrees per second)* RESET	DELTA

Parameter	Command	Options	Default
Output Filter	=FILTEN,<*x*>	0 *(disabled)* 1 *(enabled)*	1
	=FILTTYPE,A,<*x*> *(accel)* or =FILTTYPE,G,<*x*> *(gyro)*	CHEBY *(Chebyshev)* BUTTER *(Butterworth)* AVE *(Uniform Averager)*	CHEBY
	=FC20,A,<*x*> (*accel*) or =FC20,G,<*x*> (*gyro*)	Custom (*accelerometer or gyro filter coefficients*)	CHEBY
X, Y, Z Axis Definitions	=AXES, [X0], [X1], [X2], [Y0], [Y1], [Y2], [Z0], [Z1], [Z2]	Floating point values defining a 3x3 rotation matrix sets the output axes relative to the physical orientation of measurement axes (see page 6).	1 0 0 0 1 0 0 0 1
Output Synchronization	=MSYNC,<x>	EXT *(external)* IMU	IMU
Linear (Accelerometer) Data Format	=LINFMT,<x>	ACCEL DELTA RESET	ACCEL
Linear (Accelerometer) Data Units *(only applies if data output is set to delta)*	=LINUNITS,<x>	METERS *(mps)* FEET *(fps)* RESET	METERS
Message Output Format	=OUTPUTFMT,<x>	A *(36 bytes)* B *(with timestamp (40 bytes))* C *(magnetometer data interleaved (38 bytes))*	A

For more information, refer to "Appendix C: Electrical Signaling ICD" on page 31. Settings are saved and reapplied on restart. You may revert to the factory default settings at any time (see "Resetting Parameters to Factory Defaults" on page 16).

NOTE: *Changing parameters from their default values may impact performance.*

You can query the current value of any parameter by entering the corresponding “**?**” command. For example, to view the current data rate, you would enter the “?dr” command.

To enter any configuration command, the IMU must first be set to Configuration mode. In Configuration mode, the IMU stops sending data and listens for user commands (a terminal prompt indicates the IMU is ready to accept commands). To put the IMU in Configuration mode, enter the “**=config,1**” command. When you are done configuring the unit, enter the “**=config,0**” command to exit Configuration mode and return to the Normal mode of operation.

Resetting Parameters to Factory Defaults

There are two options for resetting all of the user-configurable parameters to their factory default values (see Figure 15).

Option 1: Enter the “**=rstcfg**” command in Configuration mode.

Option 2: Apply a positive RS-422-compliant voltage from pin 6 (Config-RST-In (-)) to pin 13 (Config-RST-In (+)) before applying power, and hold it at that level until the unit starts outputting data. The pins may be left disconnected until you need to perform a reset.

Figure 15: Default Values

User-Configurable Parameters	Default Value
Output Format	Output format A
Linear Format	Acceleration
Linear Units	Meters per second
Angular Units	Radians
Angular Format	Delta angle
Temperature Units	°C
Temperature Data Resolution	1°
Baud Rate	921600 baud
Data Rate	1000
Filter Type	Chebyshev
Clock Source	IMU

NOTE: *The baud rate will default for Config-RST-In; baud rate will* not *change for =rstcfg command (Rev. C or later software).*

User Commands

In addition to the configuration commands described in "Configuration Options" on page 14, the following commands are also available to the user. For more information, refer to "Appendix C: Electrical Signaling ICD" on page 31.

Figure 16: User Commands

Command	Description
?bit	Initiates a built-in test in Normal mode
?bit,2	Initiates a built-in test in Normal mode with extended diagnostic information
=config	Forces the unit into or out of Configuration mode
?config	Reports whether or not the IMU is currently running in Configuration mode
=echo *(or ?echo)*	Reports how many times the echo command has been called; useful for verifying communications to the unit
=help *(or ?help)*	Displays a list of available commands
?is	Reports the system serial number
=restart	Restarts the IMU
=rstcfg	Resets all user-configurable parameters to their factory default values
?temp	Reports the internal temperature of the IMU; detected by the controller board
=TestFilt *(or ?TestFilt)*	Tests the configured output filter response to a unit impulse
?volt	Reports all available voltages on the controller board
?ws	Reports the software versions of IMU components
?logs	Reports stored BIT diagnostic history

All commands must be entered while the IMU is in Configuration mode except "?bit", "?bit,2", *(entered in Normal mode)* and "=config" *(entered in Configuration or Normal mode)*.

Time of Validity (TOV) Output

The 1775 IMU provides an optional RS-422 differential output on the external connector (named TOV-OUT+/TOV-OUT-) to indicate the time at which the data being output on the serial port can be considered to be valid. TOV should not be used or considered valid when operating the IMU in modes other than Normal Mode(e.g., in Configuration mode). TOV signaling is based on the IMU's internal clock and shown in Figure 16.

MSYNC is an optional 1775 IMU timing synchronization method used for external control systems. An external (master synchronization) differential signal input will trigger the IMU output at its rising edge. The MSYNC digital signal supports asynchronous requests for data. Use of the external MSYNC option can affect, or be affected by other configuration settings. For more information, refer to “Appendix C: Electrical Signaling ICD” on page 31.

Figure 17: TOV Output Timing Relative to Serial Port Activity

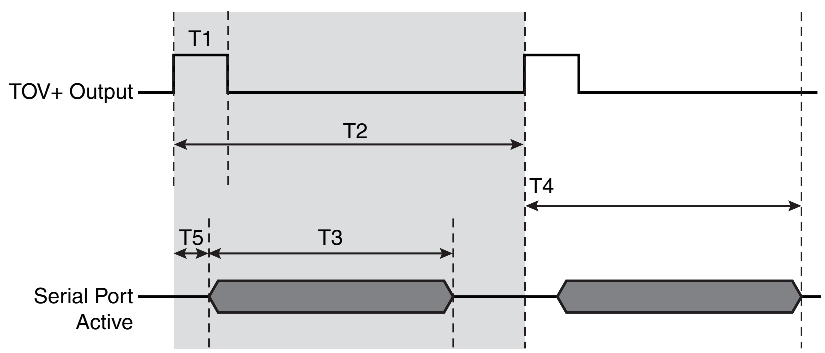


Figure 18: TOV Timing Parameters

Parameter	Description	Value
T1	TOV high	Depends on MSYNC configuration; MSYNC,IMU: high time is 10% of the TOV period; for example: at default rate of 1,000 Hz, the T1 high time will be 100 μs for internal clock mode MSYNC,EXT: high time is approximately the same as the external MSYNC signal active time
T2	TOV period	Depends on MSYNC configuration; MSYNC,IMU: Period is determined by the output data rate; for example, at default data rate of 1,000 Hz, T2 = 1000 μs MSYNC,EXT: period reflects the external MSYNC signal
T3	Duration of serial port output	Depends on output format and baud rate; approximately equal to the number of characters output multiplied by the number of bits per character (10) divided by the baud rate; for example, format A at default baud rate of 921600 Bd, T3 is approx 390 μs
T4	Time between rising edge of TOV-Out and the end of data transmission	<500 μs (at default format A and baud rate of 921600 Bd)
T5	Time between start of TOV and the start of T3	Typically 30 to 100 μs

Master Sync (External Data Request)

The 1775 IMU can accept an optional user-supplied RS-422 differential master sync input signal on pin 7 (MSync (-)) and pin 11 (MSync (+)). The IMU's output will be triggered on the rising edge of this master sync signal. *The 1775 IMU master sync signal input supports both isosynchronous and non-isosynchronous signaling methods of transmission synchronization.* For more information, refer to "Appendix C: Electrical Signaling ICD" on page 31.

Figure 19: Master Sync

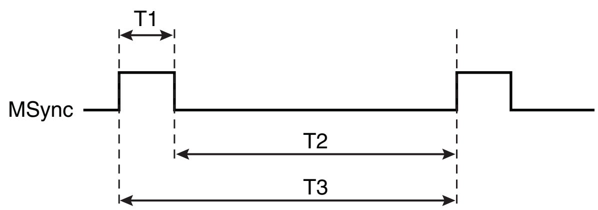


Figure 20: MSync Timing Parameters

Parameter	Description	Value
T1	MSync high	≥30 μs
T2	MSync low	≥30 μs
T3	Period between rising edges	0.2-2000 ms

To synchronize the IMU's output with an external signal on pin 7 and pin 11, enter the "**=MSYNC,ext**" command in Configuration mode. Upon initiating the "**=MSYNC,ext**" command, the IMU automatically clears any user-selected output filter and switches to the Uniform Averager setting. This allows you to use the MSync signal as an external data request for data, rather than using internally timed data output. However, you may override this behavior by choosing any output filter using the appropriate Output Filter commands provided in Figure 14 on page 14. Be sure to enter the Output Filter commands AFTER you have entered the "**=MSYNC,ext**" command.

NOTE: *Consecutive rising edges of the MSync signal must be between 0.2-2000 ms apart. Pulsing MSync faster than 0.2 ms may result in inaccurate or corrupt data output. If the IMU does not detect a rising edge within 2000 ms, it will output data upon reaching 2000 ms.*

TOV with Internal MSYNC Mode

When the IMU is providing its own data output requests based on its internal source's preconfigured rate, the unit outputs the differential TOV signal with a 10% duty cycle at the same frequency as the data output. See the timing diagram shown in Figure 17 on page 18, as well as the timing parameters in Figure 18 on page 19.

TOV with External MSYNC Active

When the external Master Synchronization Input is configured, the IMU will simply buffer (i.e., repeat) the MSYNC signal back out to the TOV signal. Therefore, the timing should closely mirror that of the external MSYNC signal.

Hardware Restart

Applying a positive RS-422-compliant voltage from pin 5 (EXT-RST (-)) to pin 14 (EXT-RST (+)) will result in a reset. These pins may be left disconnected until you need to restart the IMU.

Mounting the IMU

The 1775 IMU is easily mounted to a structure using the four ∅0.173" (∅4.39 mm) mounting holes on the base of the enclosure (see Figure 21). An alignment hole ∅0.198" (∅5.03 mm) and an alignment slot 0.218" x 0.198" (5.54 mm x 5.03 mm) are provided at the middle edge of the enclosure for alignment purposes. They are designed for ∅5.004-5.012 mm dowel pins with 0.1" (2.5 mm) protrusion.

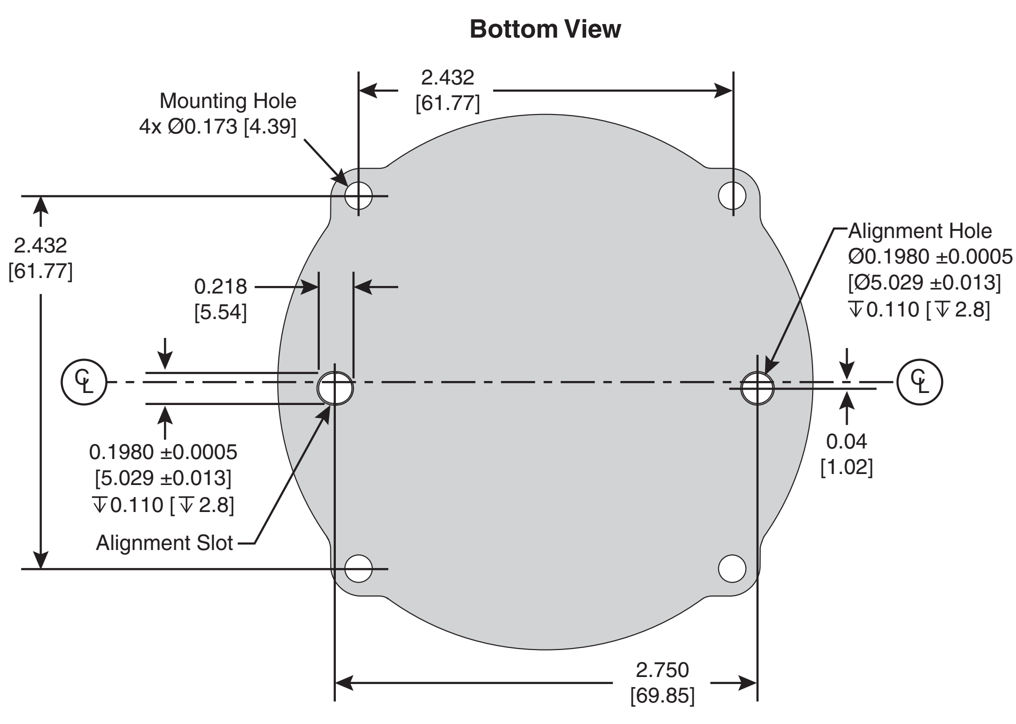
NOTE: *To ensure precise alignment, rotate the IMU clockwise before tightening the mounting screws.*

The IMU base material is aluminum with a clear chromate finish per MIL-DTL-5541, class 3. To ensure optimal heat transfer (conductive cooling) and electrical grounding through the chassis, mount the IMU base to a clean, flat, unpainted metal surface.

Also be sure to orient the IMU with the desired measurement axes. As an alternative, you may configure a rotation matrix to set the output axes relative to the physical orientation of the measurement axes (see “Configuration Options” on page 14).

NOTE: *All dimensions are shown in inches [millimeters] format.*

Figure 21: Mounting Holes (Bottom View)



Troubleshooting

This chapter explains how to diagnose basic problems.

IMPORTANT!

The 1775 IMU is supplied as a sealed unit. Breaking the QA seals voids the warranty and may violate the contract under which the unit was supplied. The warranty does not apply if the unit has been damaged by misuse or as the result of service or modification other than by KVH Industries.

Figure 22: Basic Troubleshooting

Problem	Solution
The unit does not power up.	Check the input power supply. 12 VDC (nominal) is recommended for stable performance. The supply should also draw between 3-8 W over the entire operating temperature range. If the power supply is OK, check the power cable and wiring.
The unit does not communicate.	Check the interface cable and make sure your equipment's serial port settings match the IMU's settings (see Figure 9 on page 11).
Incoherent data is streaming.	Ensure the baud rate of your interface port is set to one of the valid configurable baud rates (see Figure 9 on page 11 for details). Also make sure your parsing algorithm is correct.
The unit is not sending data at the set data rate.	Ensure the set baud rate is fast enough to support the chosen data rate (see Figure 23 on page 24). Verify with an oscilloscope.

Figure 23: Recommended Baud Rate/Data Rate Limits

Baud Rate	Maximum Data Rate (Hz)
9600	10
19200	25
38400	50
57600	100
115200	100
460800	500
576000	750
921600	1000
4147200	5000

Built-In Test (BIT)

The IMU's built-in test (BIT) monitors system performance and status to ensure it is operating within its specifications. BIT test results are output in five ways:

- **Continuous BIT** – The Continuous BIT is output as part of the IMU's output message during operation (see "Continuous BIT Status Information" on page 25).

- **Startup Extended BIT** – When the IMU is powered on, it outputs the extended BIT status message (see "Extended BIT, 2 Status Information" on page 26).

- **User-requested Extended BIT** – When you enter the "**?bit**" command in Normal mode, the IMU outputs the extended BIT status message (see "Extended BIT, 2 Status Information" on page 26).

- **User-requested Extended BIT, 2** – When you enter the "**?bit,2**" command in Normal mode, the IMU outputs expanded diagnostics information, including magnetometer readings.

NOTE: *Extended BIT, 2 may impact high-speed outputs while transmitting.*

- **BIT Log** – When BIT information is generated, a log report is created. This log is accessible by entering the "**?logs**" command in Configuration mode.

Continuous BIT Status Information

As detailed in the message structure data table example on page 12, byte 24 (message format A) or 28 (message format B and C; refer to "Appendix C: Electrical Signaling ICD" on page 31 for more information) of the IMU's output message (excluding the message header) reports the general status of the gyros and accelerometers. Converted to hexadecimal, a "77" status byte indicates normal status.

Figure 24: Status Byte Format

Datum	Bit #	Notes
Gyro X	0 (LSB)	1 = Valid data, 0 = Invalid data
Gyro Y	1	1 = Valid data, 0 = Invalid data
Gyro Z	2	1 = Valid data, 0 = Invalid data
Reserved	3	Always 0
Accelerometer X	4	1 = Valid data, 0 = Invalid data
Accelerometer Y	5	1 = Valid data, 0 = Invalid data
Accelerometer Z	6	1 = Valid data, 0 = Invalid data
Reserved	7	Always 0

Extended BIT Status Information

When the IMU is first powered on, and upon user request, the IMU outputs an extended BIT message consisting of six or eight bytes of detailed status information for diagnostics. Converted to hexadecimal, the following message indicates normal status:
"FE 81 00 AA 7F 7F 7F 7F 7F 7F 23".

Figure 25: Extended BIT Message Format

Function	Total # Bytes	Description
Header	4	0xFE8100AA
Message data	6	Refer to "Appendix C: Electrical Signaling ICD" on page 31.
Checksum	1	Calculated by accumulating the sum of each byte of data, modulo 256

Extended BIT, 2 Status Information

Upon user request, the IMU outputs an extended BIT message consisting of eight bytes of expanded status information, including magnetometer readings, for diagnostics. Converted to hexadecimal, the following message indicates normal status:
“FE 81 00 AA 7F 7F 7F 7F 7F 7F 7F 7F 23”.

Figure 26: Extended BIT, 2 Message Format

Function	Total # Bytes	Description
Header	4	0xFE8100AB
Message data	8	Refer to “Appendix C: Electrical Signaling ICD” on page 31.
Checksum	1	Calculated by accumulating the sum of each byte of data, modulo 256

Technical Support

For technical support, please email your question or a description of your problem to fogsupport@kvh.com.

KVH Industries, Inc.
Declaration of Conformity

KVH Industries, Inc., 50 Enterprise Center, Middletown, RI 02842 USA declare under our sole responsibility, that the product: KVH Inertial Measurement Units with model numbers: **1775 IMU (01-0363-01), 1750 IMU (01-0349-01, -02, -03, -21, -30), 1725 IMU (01-0382-01)** to which this declaration relates is in conformity with the following standards or other normative documents:

Environmental

• Altitude, Operational & Transport	MIL-STD-810G, Method 500.5
• Humidity, Operational/Non-Operational	MIL-STD-810G, Method 507.5
• Salt Fog, Non Operational	MIL-STD-810F, Method 509.4
• Immersion	MIL-STD-810G, Method 512.5 Procedure 1
• Sand and Dust	MIL-STD-810G, Method 510.5

EMC Emission

• FCC 47 CFR Part 15	Class B emissions requirements (USA)
• EN 61000-6-3:2007 +A1:2011	Emissions requirements for residential, commercial & light industrial environments

EMC Immunity

• EN 61000-6-1:2007	Immunity for residential, commercial and light industrial environments
• EN 61000-4-2	Electrostatic Discharge Immunity
• EN 61000-4-3	Radiated Immunity
• EN 61000-4-4	Electrical fast Transients
• EN 61000-4-5	Surge Immunity
• EN 61000-4-6	Conducted Radio Frequency Immunity
• EN 61000-4-8	Power Frequency Magnetic Field Immunity

Product Safety

• IEC 60950-1:2005 (2nd Ed) + Am 1:2009 + Am 2:2013	"Information Technology Equipment- Safety-
• CAN/CSA C22.2 No. 60950-1-2011	IT Equipment Safety Part 1: General Reqs.
• ANSI/UL 60950-1, 2nd Ed 2007	UL Standard for Safety for IT Equipment

RoHS

• RoHS 2011/65/EU (RoHS 2)	Restriction of Hazardous Substances Directive

REACH

• EU#134/2011 (Annex XIV of EC# 1907/2006)	Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH)

Reports

MIL-STD-810G (all categories listed above)	Retlif Report #R-14510-3
EMC Emissions and Immunity	Retlif Report # R-5856N-1
Product Safety	Intertek # 102259286BOX-002
RoHS/REACH	Intertek # 102439635COL-001, TUV Rheinland Report 30-Apr-2018

Signed:

Rick Jones
Quality Manager

Date: April 30, 2018

Alexandra L. Mouligné
Notary Public, State of Rhode Island
(ID No. 753884)

Place of Issue: KVH Industries, Inc.
50 Enterprise Center Middletown, RI
02842 U.S.A.

Appendix B: Warranty Information

KVH Industries Limited Warranty 1775 IMU

LIMITED WARRANTY ON HARDWARE

KVH Industries, Inc. warrants the Inertial Measurement Unit purchased against defects in materials and workmanship for a period of ONE (1) year from the date of original retail purchase by the original purchaser. If you discover a defect, KVH will, at its option, repair, replace or refund the purchase price of the product at no charge to you, provided you return it during the warranty period, transportation charges prepaid, to the factory direct.

Please attach your name, address, telephone number, a description of the problem and a copy of the bill of sale or sales receipt as proof of date of original retail purchase, to each product returned to warranty service.

This Limited Warranty does not apply if the product has been damaged by accident, abuse, misuse, or misapplication or has been modified without the written permission of KVH; if any KVH serial number has been removed or defaced; or if any factory-sealed part of the system has been opened without authorization.

THE EXPRESS WARRANTIES SET FORTH ABOVE ARE THE ONLY WARRANTIES GIVEN BY KVH WITH RESPECT TO ANY PRODUCT FURNISHED HEREUNDER; KVH MAKES NO OTHER WARRANTIES, EXPRESS, IMPLIED OR ARISING BY CUSTOM OR TRADE USAGE, AND SPECIFICALLY DISCLAIMS ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. SAID EXPRESS WARRANTIES SHALL NOT BE ENLARGED OR OTHERWISE AFFECTED BY TECHNICAL OR OTHER ADVICE OR SERVICE PROVIDED BY KVH IN CONNECTION WITH ANY PRODUCT.

KVH's liability in contract, tort or otherwise arising out of or in connection with any product shall not exceed the price paid for the product. **IN NO EVENT SHALL KVH BE LIABLE FOR SPECIAL, PUNITIVE, INCIDENTAL, TORT OR CONSEQUENTIAL DAMAGES OR LOST PROFITS OR GOODWILL (INCLUDING ANY DAMAGES RESULTING FROM LOSS OF USE, DELAY IN DELIVERY OR OTHERWISE) ARISING OUT OF OR IN CONNECTION WITH THE PERFORMANCE OR USE OR POSSESSION OF ANY PRODUCT, OR ANY OTHER OBLIGATIONS RELATING TO THE PRODUCT, EVEN IF KVH HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.**

If any implied warranty, including implied warranties of merchantability and fitness for a particular purpose, cannot be excluded under applicable law, then such implied warranty shall be limited in duration to ONE (1) YEAR from the date of the original retail purchase of this product by the original purchaser.

Some states do not allow the exclusion or limitation of implied warranties or liability for incidental or consequential damages, so the above limitations may not apply to you. This warranty gives you specific legal rights, and you may also have other rights which vary from state to state.

Appendix C: Electrical Signaling ICD

The Electrical Signaling Interface Control Document (ICD) describes in detail the serial communications, electrical, and physical interfaces between the 1775 IMU and outside systems. The ICD also provides a thorough overview of all commands, queries, and configuration options. Refer to the ICD for comprehensive details about the following:

- Overview of the electrical interface
- Description of operating modes and message formats, Time of Validity output, and MSYNC
- Instructions for conducting and interpreting the results of a Built-In Test
- Comprehensive list of all user commands, queries, and configuration options
- Description of every command and query
- Overview of data output signal processing formats

1775 Inertial Measurement Unit

External Electrical Signaling

Interface Control Document

56-0298 Rev. B

October 7, 2015

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Table of Contents

Tables

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Revision History

Date	Description	Rev
10/23/14	Document Creation	A
9/23/15	Rev. B ECO #11432	B

1 Scope

This Interface Control Document (ICD) describes the serial communications and the electrical and physical interfaces between the 1775 Inertial Measurement Unit (IMU) and the outside world.

The “1775 IMU,” also referred to as “the unit,” “the IMU,” or “the system,” is the product at large.

Other related documents include the Technical Manual (KVH part no. 54-0938) and the Interface Control Drawing (KVH part no. 99-0353).

2 Abbreviations, Acronyms and Definitions

Table 2-1: List of Abbreviations and Acronyms Used

Acronym or Abbreviation	Definition
Accel	accelerometer and acceleration
ASCII	American Standard Code for Information Interchange; a character-encoding standard that specifies 128-characters into a 7-bit binary value.
BIT	Built-in Test
Baud	Communications rate as symbols/sec (typical unit symbol is Bd); the IMU outputs at 1 bit per symbol therefore baud equates to bits/sec.
CRC	Cyclic Redundancy Check
DISC	Discrete data format, as opposed to an integer or floating-point value. For our purposes, discrete values are bit fields (e.g., bit 0 of a status byte indicates whether gyro X is outputting valid data).
DSP	Digital Signal Processor
Float	Same as SPFP
FOG	Fiber Optic Gyro
FPGA	Field Programmable Gate Array
g	Unit designation for g-force when associated with accelerometer data output
GCB	Gyro Control Board; a sub-system for gyro measurement
Gyro	Gyroscope
Hex	Hexadecimal notation. Often denoted by preceding the number with “0x”
ICB	IMU Control Board; a sub-system for overall unit control and user-interface
ICD	Interface Control Document or Interface Control Drawing
IMU	Inertial Measurement Unit
MEMS	Micro-Electro-Mechanical Systems
Modulo N	A count sequence from 0 to N-1; ex. modulo 256 would range from 0 to 255, then restart at 0.
MSYNC	Master Synchronization
RS-422	An industry standard electrical signal level interface using balanced differential pairs typically on twisted-pair wires at up to 10MBd (bits/sec) rates.
SPFP	Single Precision Floating Point (IEEE-754 Big-endian format)
SW	Software
TOV	Time of Validity

3 System Overview

The 1775 IMU is a compact, commercial strap-down inertial sensor system using KVH's advanced Fiber Optic Gyros combined with low-noise MEMS accelerometers and magnetometers. It is intended for use in precision guidance and stabilization applications where high bandwidth, low noise, and bias stability performance levels are important. The 1775 IMU is lightweight, low power, and rugged, offering accurate performance in extreme environments. Its flexible digital data and power interface is designed for ease of integration in new applications and upgrades to existing systems. It is part of a family of commercial IMUs, which includes the 1725 and 1750 IMUs, which offer the same physical package, but different price and performance specifications.

3.1 Functional Overview

The 1775 IMU is a nine-Degree of Freedom (9-DOF) inertial sensor package containing three accelerometers, three gyroscopes, a 3-D magnetometer, and internal temperature sensors. All sensors are directly fixed to the housing frame.

Internally, three single-axis interferometric Fiber Optic Gyros (FOGs) are used to measure the angular rate at three orthogonal axes. The 1775 IMU uses three single-axis MEMS accelerometers to measure linear Acceleration along these orthogonal axes. A temperature compensated, three-axis integrated circuit (IC) magnetometer provides low field (< 10 Gauss) magnetic sensing and compensation of magnetic disturbances.

The 1775 IMU provides a full-duplex, asynchronous, RS-422 level serial interface for signal communications to an external control system(s). The serial communications interface transmits sensor and status data from the IMU and receives commands and data from the user. Serial baud is configurable and is stored in non-volatile/persistent memory. The digital control signals and status use RS-422 differential signaling. Digital control signal pairs are External Reset (In), Time of Validity (Out), Master Synchronization Clock (In), and Configuration Software Reset (In).

The 1775 IMU electronics offers user options for changing its run-time configuration, such as operating services (e.g., filters, serial communications, and other characteristics as described in this document).

3.2 Electrical Interface Overview

The 1775 IMU uses a MIL-DTL-83513 Micro-D interface connector located on the top face of the housing. For more information, refer to the Interface Control Drawing (KVH Drawing 99-0353) part of which is copied below, for easy reference (see Figure 3-1). Figure 3-2 below shows the signals and associated pin numbers.

Figure 3-1: 1775 IMU Interface Block Diagram

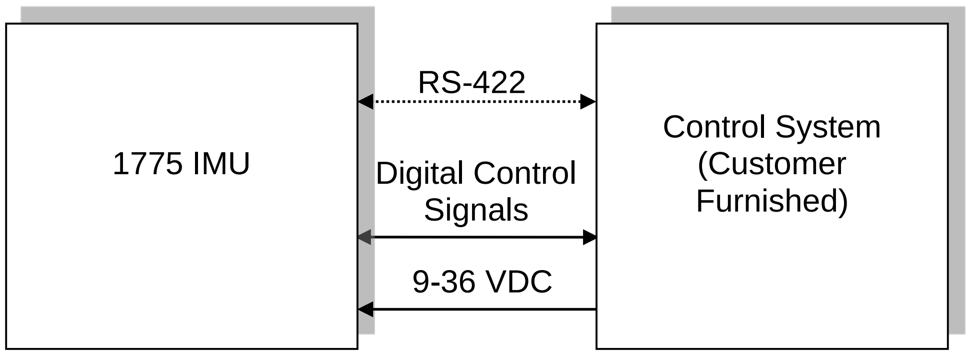
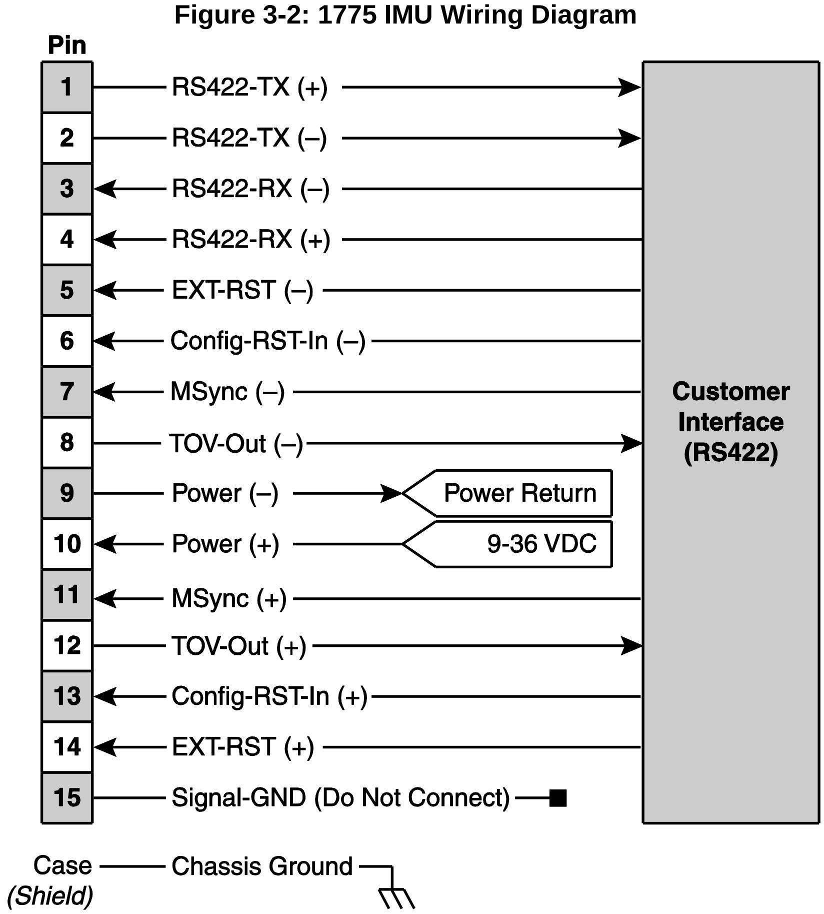


Figure 3-2: 1775 IMU Wiring Diagram



3.2.1 Input Power

The 1775 IMU accepts input power of 9-36 VDC (max) through the Micro-D interface connector pin 10 (**Power (+)**). Typical voltage input ranges 10 to 32 VDC. Typical power consumption is 5 Watts, 8 Watts maximum.

3.2.2 Electrical Grounding

The 1775 IMU has a separate common ground (**Power (-)**) and chassis ground. The common ground is used for input power return and electrical signals. It is located on pin 9 of the Micro-D interface connector (see KVH Drawing 99-0353). Chassis ground is through the IMU metallic case via one of the mounting holes for personnel safety (electric shock) and EMI (noise) emission/susceptibility immunity.

NOTE: A signal ground reference (Signal-GND) is also available on the I/O connector at pin 15 (see KVH Drawing 99-0353 and Figure 3-2). This pin is reserved for factory testing and may be subject to change in the future. It should not be connected to the power return externally.

3.2.3 Serial port Interface

The 1775 IMU provides a full-duplex, differential RS-422 serial data port for communication to connected test equipment, control, guidance, or navigation electronics. The RS-422 serial port transmits sensor and status data and receives commands and control data for configuration, test, or maintenance. Multiple baud rates are supported.

3.2.4 Auxiliary Signals

The 1775 IMU provides a number of auxiliary signals as differential RS-422 level inputs and outputs for the following functions:

a) Reset the system
b) Set all configuration options to the default value
c) Master Synchronization Input (e.g., external data request)
d) Time Of Validity (TOV) indicator

3.3 Operating Modes

The 1775 IMU has two operating modes: Normal and Configuration Mode. When initialized, the IMU runs in Normal Mode by default. The operating mode can be changed to the user Configuration Mode through serial port commands to allow changes to the IMU configuration settings.

Table 3-1: Operating Modes

Operating Mode	Description
Normal Mode (default)	The unit will output binary (non-human readable) data messages at the preconfigured rate. The data messages will have the formats specified and typically include a header, message body, and CRC code (see Section 5). The unit will listen for permissible commands as simple ASCII text.
Configuration Mode	The unit will stop output of binary data and will respond to any commands and queries that are sent (see Section 6). This mode allows the user to configure the unit and query its status prior to returning to normal mode. Interaction is simple character-based using ASCII encoded text making it easy to communicate with terminal emulators.

3.4 Built-In Test

The 1775 IMU has Built-in-Test (BIT) functions for: a) power-up built-in self-test, b) continuous built-in self-test, and c) user-requested built-in self-test. BIT verifies operational status of essential IMU services and resources including microprocessors, memory, software, power levels, sensor status, timing, temperature, and communications. BIT outputs include error conditions or information to aid diagnostics.

Power-up BIT is performed at startup. Power-up BIT results are output via the serial port using a BIT message (see Section 5.3). Continuous BIT is performed during normal operation to indicate the validity status of each sensor data message. Continuous BIT results are output via the serial port in a message status byte. A user-requested BIT may be initiated any time through a serial data port command.

4 Data Communications and Unit Control

The 1775 IMU provides a digital interface for the following functions:

- Output of sensor data and status messages including built-in test messages.
- Receipt of external commands to configure and control the IMU assembly.
- Data output control, timing, and reset functions.

4.1 Interface Connector

The 1775 IMU is equipped with a type MIL-DTL-83513 15-pin (male-pin) Micro-D interface connector for data communications and power. Table 4-1 below describes the function of each pin. These were also shown in Figure 3-2.

Table 4-1: Electrical Interface Signals

Pin # Number	Pin Name	Description	Comments
1	RS422-TX+	Output: differential positive	RS-422 serial port for primary data output and command input; the commands that can be sent to the RS-422 port are listed in Section 7.2
2	RS422-TX-	Output: differential negative	
3	RS422-RX-	Input: differential negative	
4	RS422-RX+	Input: differential positive	
11	MSYNC+	Input: differential positive	Master Synchronization for external data request (see Section 10.3)
7	MSYNC-	Input: differential negative	
13	CONFIG-RST-IN+	Input: differential positive	Configuration Reset (see Section 10.1)
6	CONFIG-RST-IN-	Input: differential negative	
14	EXT-RST+	Input: differential positive	External Reset (see Section 10.2)
5	EXT-RST-	Input: differential negative	
12	TOV-OUT+	Output: differential positive	Time Of Validity (TOV) (See Section 11)
8	TOV-OUT-	Output: differential negative	
10	POWER +	Power positive	10-32 VDC type; (9-36 VDC max) (see Figure 3-2)
9	POWER -	Power return and signal ground	
15	NC	Do Not Connect	For factory/future use

4.2 Character Data Format

Communications to/from the unit use the RS-422 serial port connections defined in Table 4-1. The message characters are comprised of words of 10 bits: one start bit, eight data bits, one stop bit, and no parity (8-N-1). The default baud rate is listed in Section 10.

When in Configuration Mode, the characters listed in Table 4-2 are reserved for use as delimiters. No other characters are reserved in any mode. The character set in use is a subset of standard ASCII. The only characters that are used are those with values between 0x20 and 0x7E, as well as any listed in Table 4-2. All other characters are unused.

Table 4-2: Reserved Characters in Human-Readable Modes

Character	ASCII Hex Code Value	Purpose
<CR>[1] (carriage return)	0x0D	End of command delimiter
<LF>[1] (line feed)	0x0A	End of command delimiter
Note 1: A carriage return, a line feed, or both are all valid end of command delimiters.		

When in Configuration Mode, either an illegal character may be ignored or the unit's response will indicate an error and possibly suggest the correct message syntax.

When in Normal Mode, user input commands or queries and commands that include illegal characters will typically be ignored without any response. However, a few special input commands are permitted as ASCII text.

When in Normal Mode, the data output is typically in binary format (not ASCII encoded) and there are no reserved characters; all characters from 0x00 to 0xFF are legal at all times. (See Section 5 for a description of the output in Normal Mode.)

5 Normal (Default) Mode Messages

5.1 Description

After the unit powers up and completes its initialization routines, it will place itself into Normal Mode and output a single BIT message, followed by repeated periodic output of motion data messages. Typically, the unit will output data at the previously configured data rate, although user-driven data output timing is supported. The output data is in binary format and is not human readable within typical terminal emulator programs (i.e., it is not ASCII encoded text).

While outputting data in one of the Normal Mode binary formats (for example, Format A, shown in Table 5-1 and Table 5-2) the unit will listen for ASCII commands, so that a user can simply type in commands using a terminal emulator program (e.g., RealTerm or equivalent). The available commands are shown in Table 7-1. Most commands are not recognized in Normal Mode and there will be no response from the unit unless it is permitted in Normal Mode. If one of the permissible subset of commands is recognized (e.g., =config,1 or ?bit), then the unit will respond appropriately.

The unit outputs two basic message types while in Normal Mode. The first type of output message carries sensor data and status and is output at the configured data rate in one of the available data formats. (See Section 5.2 for a description of the available data formats.) The second output message type contains BIT results, which are output at power-up and on user command. (See Section 5.3 for a description of the BIT data formats.)

Normal Mode output data messages typically include a header code, message packet and a CRC code. The user should ignore any output from the unit that has an invalid header code or bad CRC. Binary output follows the big-endian format convention.

The header codes are typically unique bit patterns that can be used to synchronize to the binary bit stream. This allows operation with a typical computer serial port and RS-422 converter. It is also possible, but not required to use the TOV output as a synchronization method to the binary data output when using other host systems.

5.2 Normal Mode Data Output Formats

Data Format A (see Table 5-1 and Table 5-2) is the standard or default 1775 IMU message output. Format B (see Table 5-3 and Table 5-4) is an optional format with timestamp information. Format C (see Table 5-5 and Table 5-6) is an optional format that is similar to Format A with magnetic field strengths multiplexed with temperature.

Each format includes a modulo 128 counter that increments with each data output message and wraps back to 0 after reaching 127. This can be used to verify sequential data reception and to decode any associated multiplexed item data.

Each format includes a unique header pattern that can be used to identify and synchronize to the binary bitstream. An alternative for synchronization would be to use the TOV output signal to indicate the start of an output message.

Table 5-1: Normal Operating Mode Message Format A
(Default binary data output format)

Item	**Byte Numbers**	**Description**
Header	1-4	Always 0xFE81FF55 (transmitted 0xFE first)
Message Data	5-32	(refer to Table 5-2)
CRC (*Cyclic Redundancy Check*)	33-36	(refer to Table 5-9)
TOTAL	*36*	

Table 5-2: Normal Operating Mode Data Format A
(Default binary data output format)

Datum	**Byte Numbers**	**Data Type***	**Units**	**Notes**
X rotational data	5,6,7,8	SPFP	Radians or degrees, selectable	MSB (Byte 5) is output first; delta angle or rate of rotation, selectable
Y rotational data	9,10,11,12	SPFP	Radians or degrees, selectable	MSB (Byte 9) is output first; delta angle or rate of rotation, selectable
Z rotational data	13,14,15,16	SPFP	Radians or degrees, selectable	MSB (Byte 13) is output first; delta angle or rate of rotation, selectable
X Acceleration	17,18,19,20	SPFP	g	MSB (Byte 17) is output first
Y Acceleration	21,22,23,24	SPFP	g	MSB (Byte 21) is output first
Z Acceleration	25,26,27,28	SPFP	g	MSB (Byte 25) is output first
Status	29	DISC	1 = valid data 0 = invalid data	(refer to Table 5-8)
Sequence number	30	UINT8	0-127	Increments for each message and resets to 0 after 127
Temperature	31,32	INT16	°C, 1/100 °C, °F, 1/100 °F, selectable	

* *SPFP = Single Precision Floating Point (IEEE-754 Big-endian format); DISC = Discrete Data; UINT8 = Unsigned 8-bit integer; INT16 = Signed 16-bit integer*

Table 5-3: Normal Operating Mode Message Format B

Item	Byte Numbers	Description
Header	1-4	Always 0xFE81FF56 (transmitted 0xFE first)
Message Data	5-36	(refer to Table 5-4)
CRC (Cyclic Redundancy Check)	37-40	(refer to Table 5-9)
TOTAL	*40*	

Table 5-4: Normal Operating Mode Data Format B

Datum	Byte Numbers	Data Type*	Units	Notes
X rotational data	5, 6, 7, 8	SPFP	Radians or degrees, selectable	MSB (Byte 4) is output first; delta angle or rate of rotation, selectable
Y rotational data	9, 10, 11, 12	SPFP	Radians or degrees, selectable	MSB (Byte 8) is output first; delta angle or rate of rotation, selectable
Z rotational data	13, 14, 15, 16	SPFP	Radians or degrees, selectable	MSB (Byte 12) is output first; delta angle or rate of rotation, selectable
X Acceleration	17, 18, 19, 20	SPFP	g	MSB (Byte 16) is output first
Y Acceleration	21, 22, 23, 24	SPFP	g	MSB (Byte 20) is output first
Z Acceleration	25, 26, 27, 28	SPFP	g	MSB (Byte 24) is output first
Timestamp	29, 30, 31, 32	UINT32	Microseconds	MSB (Byte 28) is output first
Status	33	DISC	1 = valid data 0 = invalid data	(refer to Table 5-8)
Sequence number	34	UINT8	0-127	Increments for each message and resets to 0 after 127
Temperature	35,36	INT16	°C, 1/100 °C, °F, 1/100 °F, selectable	

* *SPFP = Single Precision Floating Point (IEEE-754 Big-endian format); DISC = Discrete Data; UINT8 = Unsigned 8-bit integer; INT16 = Signed 16-bit integer*

Table 5-5: Normal Operating Mode Message Format C

Item	Byte Numbers	Description
Header	1-4	Always 0xFE81FF57 (transmitted 0xFE first)
Message Data	5-34	(refer to Table 5-6)
CRC (Cyclic Redundancy Check)	35-38	(refer to Table 5-9)
TOTAL	*38*	

Table 5-6: Normal Operating Mode Data Format C

Datum	Byte Numbers	Data Type*	Units	Notes
X rotational data	5, 6, 7, 8	SPFP	Radians or degrees, selectable	MSB (Byte 4) is output first; delta angle or rate of rotation, selectable
Y rotational data	9, 10, 11, 12	SPFP	Radians or degrees, selectable	MSB (Byte 8) is output first; delta angle or rate of rotation, selectable
Z rotational data	13, 14, 15, 16	SPFP	Radians or degrees, selectable	MSB (Byte 12) is output first; delta angle or rate of rotation, selectable
X Acceleration	17, 18, 19, 20	SPFP	g	MSB (Byte 16) is output first
Y Acceleration	21, 22, 23, 24	SPFP	g	MSB (Byte 20) is output first
Z Acceleration	25, 26, 27, 28	SPFP	g	MSB (Byte 24) is output first
Temperature; X, Y and Z magnetic data	29, 30, 31, 32	The temperature and the three axes of the magnetic field data are output in bytes 24-27 in a sequence modulo of four (refer to Table 5-7).		
Status	33	DISC	1 = valid data 0 = invalid data	(refer to Table 5-8)
Sequence number	34	UINT8	0-127	Increments for each message and resets to 0 after 127

* *SPFP = Single Precision Floating Point (IEEE-754 Big-endian format); DISC = Discrete Data; UINT8 = Unsigned 8-bit integer; INT16 = Signed 16-bit integer*

Table 5-7: Temperature and Magnetic Output Sequence (See Data Format C)

Modulo Sequence	Data Type	Units	Data Output
0	SPFP	°C or °F, selectable	Temperature
1	SPFP	Gauss	X axis magnetic data
2	SPFP	Gauss	Y axis magnetic data
3	SPFP	Gauss	Z axis magnetic data

NOTE: Temperature is output as a single-precision float, but in earlier versions of software this may be reported without fractional precision. Use the 100ths of degree configuration of the =TEMPUNITS command to increase precision if needed.

Table 5-8: Status Byte Format
(Default binary data output format)

Function	Bit Number	Notes
Gyro X status	0 (LSB)	1 = Valid data, 0 = Invalid data
Gyro Y status	1	1 = Valid data, 0 = Invalid data
Gyro Z status	2	1 = Valid data, 0 = Invalid data
Reserved	3	Always 0
Accelerometer X status	4	1 = Valid data, 0 = Invalid data
Accelerometer Y status	5	1 = Valid data, 0 = Invalid data
Accelerometer Z status	6	1 = Valid data, 0 = Invalid data
Reserved	7	Always 0

*NOTE: In addition to this general status information, an extended built-in test (BIT) may be initiated at any time by entering the "**?bit**" command. (Extended BIT data is also output whenever the IMU is first powered on.) The extended BIT provides six bytes of diagnostic data, which are defined in Table 5-12 through Table 5-19.*

The constant zero bits are intentionally inserted in the status to prevent it from taking on a value that, combined with the sequence number and temperature, could be misinterpreted as a message header code.

Table 5-9: CRC Format
(Default binary data output format)

Parameter	Value
Width	32
Polynomial	0x04C11DB7
Reflect In	False
XOR In	0xFFFFFFFF
Reflect Out	False
Width	32

The output data is aligned to an end-user configurable axis of orientation. By default, axes $X_{The\ user}$, $Y_{The\ user}$ and $Z_{The\ user}$ are equal to X_{Sensor}, Y_{Sensor}, and Z_{Sensor}, respectively. The BIT status, however, is always indicated relative to the physical sensors inside the device (axes X_{Sensor}, Y_{Sensor}, and Z_{Sensor}). The end-user is responsible for determining what course of action should be taken if one or more of the input axes fail. (See Section 9 for a description of the input axes and see Section 8.1 for details about the =AXES command needed to change the alignment of the axes as desired.)

5.2.1 Sample Output

An example data output string of Format A follows. In this example, all sensor outputs are assumed to be valid. Spaces are shown for ease of reading and the ASCII text values displayed would be replaced with the hexadecimal values they represent. (See Table 5-10 for a detailed description of the string.)

FE 81 FF 55 37 A9 6A 6E 38 58 6C 1F B7 5B F8 62 BF 80 3E 78 BB 65 0D 28 3B 0A 37 AC 77 3D 00 28 4B FA 34 D8

Table 5-10: Breakdown of Sample Output

Item	Hex Data	Interpreted Data	Units
Header	0xFE81FF55	N/A	Header code for Format A
Gyro X	0x37A96A6E	2.019593E-5	Configuration dependent (default: delta radians)
Gyro Y	0x38586C1F	5.159911E-5	Configuration dependent (default: delta radians)
Gyro Z	0xB75BF862	-1.3111248E-5	Configuration dependent (default: delta radians)
Accel X	0xBF803E78	-1.0019064E0	g
Accel Y	0xBB650D28	-3.34950469E-3	g
Accel Z	0x3B0A37AC	2.1090312E-3	g
Status	0x77	All sensors are valid	DISC
Sequence #	0x3D	74	Modulo 128 count
Temperature	0x0028	40	Configuration dependent (default: ºC)
CRC	0x4BFA34D8	1274688728	N/A

5.3 Built-In Test and Extended Built-In Test

During normal operation, if the user wants the unit to perform a BIT, they must request it using the “?bit” command or the extended “?bit,2” command, described in Section 8. The output of a BIT is described in Table 5-11. The user-requested ?bit results are performed without affecting real-time operations or high-speed message output. The user-requested ?bit,2 results contain extended test diagnostics information and may impact high-speed message outputs during the extended BIT communication time.

Table 5-11: Normal Mode BIT Output

Item	Number of Bytes	Description
Header	4	Always 0xFE8100AA or 0xFE8100AB (transmitted 0xFE first)
Test Results	6 bytes or 8 bytes	The data is described in Table 5-12 through Table 5-19. Is 6 bytes for ?bit (header 0xFE8100AA) Is 8 bytes for ?bit,2 (header 0xFE8100AB)
Checksum	1	The checksum will be calculated by accumulating the sum of each byte of data, modulo 256.

The results of each test are indicated with a 1-bit pass/fail flag, 1 indicating a “pass” condition, while a 0 indicates reduced confidence in the measurement (“fail”). (See Table 5-12 through Table 5-19 for the complete test list.) Most users do not need the granularity provided by these six bytes, but the extra data is useful for diagnostic purposes. (See Table 5-21 for which bits are relevant for each sensor.)

In the following tables (Table 5-12 through Table 5-19), the reserved bits are the most significant bits of their respective bytes. Byte 0 is the first transmitted, byte 7 is the last. The number in parentheses in the “Bit Number” column is the number referenced by Table 5-20.

Table 5-12: Test Results Byte 0

Datum	Bit Number	Notes (Unless Otherwise Noted: 1 = PASS, 0 = FAIL)
Gyro X SLD	0 (0)	
Gyro X MODDAC	1 (1)	
Gyro X Phase	2 (2)	
Gyro X Flash	3 (3)	
Gyro Y SLD	4 (4)	
Gyro Y MODDAC	5 (5)	
Gyro Y Phase	6 (6)	
Constant Zero	7 (7)	Always 0

Table 5-13: Test Results Byte 1

Datum	Bit Number	Notes
Gyro Y Flash	0 (8)	
Gyro Z SLD	1 (9)	
Gyro Z MODDAC	2 (10)	
Gyro Z Phase	3 (11)	
Gyro Z Flash	4 (12)	
Accel X Status	5 (13)	
Accel Y Status	6 (14)	
Constant Zero	7 (15)	Always 0

Table 5-14: Test Results Byte 2

Datum	Bit Number	Notes
Accel Z Status	0 (16)	
Reserved	1 (17)	Always 1
Gyro X SLD Temperature Status	2 (18)	
Reserved	3 (19)	Always 1
Gyro Y SLD Temperature Status	4 (20)	
Reserved	5 (21)	Always 1
Gyro Z SLD Temperature Status	6 (22)	
Constant Zero	7 (23)	Always 0

Table 5-15: Test Results Byte 3

Datum	Bit Number	Notes
Accel X Temperature Status	0 (24)	
Accel Y Temperature Status	1 (25)	
Accel Z Temperature Status	2 (26)	
GCB Temperature Status	3 (27)	
IMU Temperature Status	4 (28)	
GCB DSP SPI Flash Status	5 (29)	
GCB FPGA SPI Flash Status	6 (30)	
Constant Zero	7 (31)	Always 0

Table 5-16: Test Results Byte 4

Datum	Bit Number	Notes
IMU DSP SPI Flash Status	0 (32)	
IMU FPGA SPI Flash Status	1 (33)	
GCB 1.2V Status	2 (34)	
GCB 3.3V Status	3 (35)	
GCB 5V Status	4 (36)	
IMU 1.2V Status	5 (37)	
IMU 3.3V Status	6 (38)	
Constant Zero	7 (39)	Always 0

Table 5-17: Test Results Byte 5

Datum	Bit Number	Notes
IMU 5V Status	0 (40)	
IMU 15V Status	1 (41)	
GCB FPGA Status	2 (42)	
IMU FPGA Status	3 (43)	
Hi-Speed SPORT Status	4 (44)	
Aux SPORT Status	5 (45)	
Sufficient Software Resources	6 (46)	
Constant Zero	7 (47)	Always 0

Table 5-18: Test Results Byte 6 - ?bit,2 Command Only

Datum	Bit Number	Notes
Gyro EO Volts Positive	0 (48)	
Gyro EO Volts Negative	1 (49)	
Gyro X Volts	2 (50)	
Gyro Y Volts	3 (51)	
Gyro Z Volts	4 (52)	
ICB Magnetics Field	5 (53)	
ICB Magnetics Set/Reset Offset Field	6 (54)	
Reserved	7 (55)	Always 0

Table 5-19: Test Results Byte 7 - ?bit,2 Command Only

Datum	Bit Number	Notes
GCB ADC Comms	0 (56)	
MSYNC External Timing	1 (57)	
Reserved	2 (58)	Always 1
Reserved	3 (59)	Always 1
Reserved	4 (60)	Always 1
Reserved	5 (61)	Always 1
Reserved	6 (62)	Always 1
Reserved	7 (63)	Always 0

To determine the status of a given sensor, ensure that each bit listed in Table 5-20 is set to 1.

Table 5-20: Validity Test Bits For Each Sensor

Sensor	Bits Indicating Degraded Confidence	Bits Indicating Zero Confidence
Accel X	24, 28, 32, 33, 37, 38	13, 40, 43
Accel Y	25, 28, 32, 33, 37, 38	14, 40, 43
Accel Z	26, 28, 32, 33, 37, 38	16, 40, 43
Gyro X	17, 18, 27, 29, 30, 34, 35	0, 1, 2, 3, 36, 42, 44, 45
Gyro Y	19, 20, 27, 29, 30, 34, 35	4, 5, 6, 8, 36, 42, 44, 45
Gyro Z	21, 22, 27, 29, 30, 34, 35	9, 10, 11, 12, 36, 42, 44, 45

5.3.1 Sample BIT Output

A sample BIT output string follows. In this example, the gyro X Flash and gyro X SLD (light, source) Temperature tests have failed BIT. Spaces are shown for ease of reading and the ASCII text values displayed would be replaced with the hexadecimal values they represent. (See Table 5-21 for a detailed description of the string.)

FE 81 00 AA 77 7F 7B 7F 7F 7F 1E

Table 5-21: Breakdown of Sample BIT Output - ?bit

Item	Hex Data	Interpreted Data
Header	0xFE8100AA	N/A
BIT 0	0x77	Gyro X Flash Failed
BIT 1	0x7F	All good
BIT 2	0x7B	Gyro X FOG Temperature Failed
BIT 3	0x7F	All good
BIT 4	0x7F	All good
BIT 5	0x7F	All good
Checksum	0x1E	N/A

5.3.2 Sample BIT,2 Output

A sample BIT output string follows. In this example, the magnetic sensor operating limits (bias) exceeds calibrated limits. In addition, the gyro Y Voltage detected a voltage that is outside accepted ranges. Spaces are shown for ease of reading and the ASCII text values displayed would be replaced with the hexadecimal values they represent. (See Table 5-22 for a detailed description of the string.)

FE 81 00 AB 7F 7F 7F 7F 7F 7F 37 7F DA

Table 5-22: Breakdown of Sample BIT Output - ?bit,2

Item	Hex Data	Interpreted Data
Header	0xFE8100AB	N/A
BIT 0	0x7F	All good
BIT 1	0x7F	All good
BIT 2	0x7F	All good
BIT 3	0x7F	All good
BIT 4	0x7F	All good
BIT 5	0x7F	All good
BIT 6	0x37	SR MAG Offset Failed GCB Y Volts Failed
BIT 7	0x7F	All good
Checksum	0xDA	N/A

6 User Configuration Mode

Configuration Mode is intended for use by installers to configure the operation for their application and for field technicians who need to perform diagnostics on the unit. It will allow users to set and/or query configuration parameters, including but not limited to the following:

- Baud rate of the main serial communications interface
- Data rate of the system transmissions during Normal Mode
- Data output request, source – data transmission relative to an internal clock or external synchronization signal
- Data message format – selects from Normal Mode output data formats
- Linear output format – acceleration or delta velocity
- Rotational output format – angular rate of rotation or delta [incremental] angle
- Axis orientation – adjusts reference frames relative to the default axes or directions (+/-)
- Output data filters – adjusts accelerometer and gyro filters independently
- Units – select degrees vs. radians or Celsius vs. Fahrenheit
- Temperature data resolution – degrees or 100ths of degrees
- Extended BIT test
- Bit log – accesses logged BIT history from startup and extended BIT records
- Serial numbers and software revision information

In Configuration Mode, the unit does not output data unless prompted by the user and it communicates in ASCII encoded text for use with standard terminal emulation programs. The summary list of commands is shown in Table 7-1.

7 Commands and Queries

All commands and their responses are terminated with either one or both of the ASCII codes for a carriage return (often symbolized as <CR> or ‘\r’ and ASCII code 0x0D) or a line feed (<LF> or ‘\n’ and ASCII code 0x0A). Command and response parameters are delimited using the comma character (‘,’, ASCII code 0x2C).

Input commands are case-insensitive. Responses to commands will be in all upper case (capital letters) unless otherwise indicated.

All commands are prefixed with either the ‘?’ or the ‘=’ character. The ‘?’ character indicates that the command is a query (a request for data). The ‘=’ character indicates a command and the unit will perform an action.

All commands have responses unless otherwise indicated. By default, commands to the unit will generate a response that is identical to the command itself, except that the ‘=’ prefix character will not be transmitted in the response. By default, queries to the unit will receive a response that is lacking the ‘?’ prefix character, has the full text of the command, and then provides the answer to the query, allowing ease of automation and a positive feedback mechanism for anyone manually entering commands. Deviations from this default are described in the subsections below.

Invalid commands are ignored in Normal Mode. When in Configuration Mode, unknown or unaccepted input commands will result in a response message starting with the word “INVALID,” followed by an echo of the string received by the IMU.

Invalid input parameters (e.g., out of range value, unexpected numeric argument, etc.) to a recognized command keyword will result in a prompt for the user starting with the keyword “USAGE” followed by a description of how to use the command or with the keyword “ERROR” with a brief description. These responses are intended for a human reader, not for an automated system. Automated systems that detect a USAGE or ERROR response may need to request operator assistance due to a likely communications problem (e.g., incorrect programming, intermittent cable connection, cable crosstalk, etc., or simply retry the command).

The users should not rely on future preservation of existing responses or observed behavior to undefined commands or out of range parameters since the behavior may change in future firmware versions.

Most commands will result in parameters being stored in non-volatile memory and recalled on the next reset/power-on. Exceptions will be described in the command descriptions below. Command defaults can be restored by command or by an input signal to the interface.

7.1 Command Definition Conventions

In the following command description sections, the following conventions will be used:

- Any parameter surrounded by square brackets ([example]) is a required parameter name, which will be accompanied by an additional description
- Any parameter surrounded by angle brackets (<example>) indicates a set of acceptable values
- Multiple parameters with a "|" separator indicate acceptable discrete values (e.g., <0|1> indicates that only the values 0 or 1 are acceptable)
- Multiple parameters with "-" separator indicate an inclusive range of acceptable values (e.g., <1-1000> indicates a parameter in the range of 1 through 1000, inclusive, is acceptable)
- Optional parameters are described in command descriptions
- Where more complicated alternatives are used, they may be shown in a separate usage line definition
- In the command line usage and responses, the terminating <CR> and <LF> symbols are implied and not shown
- Typically Boolean type parameters that accept a value as <0|1> are defined as FALSE or OFF if 0 and TRUE or ON if 1

Numeric parameters may be ASCII encoded string representations of one of either integer or floating-point values (i.e., floats or SPFP) depending on the specific command. Integer type values, when received as float types, will typically be rejected with a usage response. Floating-point type parameters may typically be entered as integers (without decimal places). Exponential notation is accepted also (e.g., 1.2345E-5 instead of 0.000012345). Typically, single precision float values in IEEE-754 format are only precise to approximately eight places after the decimal point.

7.2 Command List

All commands are listed below, along with the operating modes where they are available. A "Y" indicates that the command is available. Details of each command are in a later section.

Table 7-1: Summary of Commands

String	Command Description	Normal Mode	Configuration Mode
=axes	Sets the X, Y and Z output axis orientations relative to default sensor reference frame; applies only to gyros and accelerometers		Y
?axes	Gets the X, Y and Z output axis orientations relative to default sensor reference frame; applies only to gyros and accelerometers		Y
=baud	Sets the baud rate of the system		Y
?baud	Gets the baud rate of the system		Y
?bit	Performs a built-in-test (similar to the self-test) while continuing to gather and output data	Y	
=config	Forces the unit into or out of Configuration Mode	Y	Y
?config	Queries if the unit is in Configuration Mode		Y
=dr	Sets the output data rate of the system when in Normal Mode		Y
?dr	Gets the output data rate of the system when in Normal Mode		Y
=echo	Useful only for verifying communications with the unit		Y
?echo	Same as =echo		Y
=fc20	Set filter coefficients		Y
?fc20	Get filter coefficients		Y
=filten	Enables/disables the filter		Y
?filten	Gets whether the filter is enabled or disabled		Y
=filttype	Set the filter type		Y
?filttype	Gets the filter type		Y
=help	Prints a list of the available commands		Y
?help	Same as =help		Y
?is	Gets the serial number of the system		Y
=linfmt	Sets the linear format of the Normal Mode output		Y
?linfmt	Gets the linear format of the Normal Mode output		Y
=linunits	Sets the linear units of the Normal Mode output		Y
?linunits	Gets the linear units of the Normal Mode output		Y
?logs	Gets the logs written to flash		Y
=msync	Sets the device to an internal or external signal/clock		Y
?msync	Gets whether the device is set to an external signal/clock		Y
=outputfmt	Sets the message output format in Normal Mode		Y
?outputfmt	Gets the message output format in Normal Mode		Y
=restart	Performs a restart of the system		Y
=rotfmt	Sets the rotational format of the Normal Mode output		Y
?rotfmt	Gets the rotational format of the Normal Mode output		Y
=rotunits	Sets the rotational units of the Normal Mode output		Y
?rotunits	Gets the rotational units of the Normal Mode output		Y
=rstcfg	Resets all user configuration options to factory defaults		Y
?temp	Gets the temperature of the unit		Y

String	Command Description	Normal Mode	Configuration Mode
=tempunits	Sets the output temperature units		Y
?tempunits	Gets the output temperature units		Y
=testfilt	Tests the filter that's currently implemented		Y
?testfilt	Same as =testfilt		Y
?volt	Gets all voltages on internal power rails		Y
?ws	Gets the software versions		Y

8 Command Descriptions

8.1 =axes

8.1.1 Description

This command sets the alignment axes relative to the physical orientation of the measurement axes. This allows the unit to measure motion in three arbitrarily orthogonal axes instead of being locked into the physical orientation axes. This command only applies to the gyros and accelerometers, not the magnetometers. In addition, this does not affect the axis reference for the BIT status. The new matrix values are stored persistently until the defaults are restored. Any 3x3 matrix will be accepted; the user is responsible for ensuring that the matrix is a valid rotation matrix.

8.1.2 Usage

=AXES,[X_0],[X_1],[X_2],[Y_0],[Y_1],[Y_2],[Z_0],[Z_1],[Z_2]

[X_{0-0}],[Y_{0-1}],[Z_{0-2}] are floating-point values and define a 3x3 rotation matrix.

The matrix is applied as follows:

$$\begin{bmatrix} X_0 & X_1 & X_2 \\ Y_0 & Y_1 & Y_2 \\ Z_0 & Z_1 & Z_2 \end{bmatrix} \begin{bmatrix} X_{Sensor} \\ Y_{Sensor} \\ Z_{Sensor} \end{bmatrix} = \begin{bmatrix} X_{User} \\ Y_{User} \\ Z_{User} \end{bmatrix}$$

Where X_{Sensor}, $Y_{Sensor,}$ and Z_{Sensor} are the sensing axes, $X_{The\ user}$, $Y_{The\ user}$, $Z_{The\ user}$ are the user-defined output axes. The default matrix is:

1 0 0
0 1 0
0 0 1

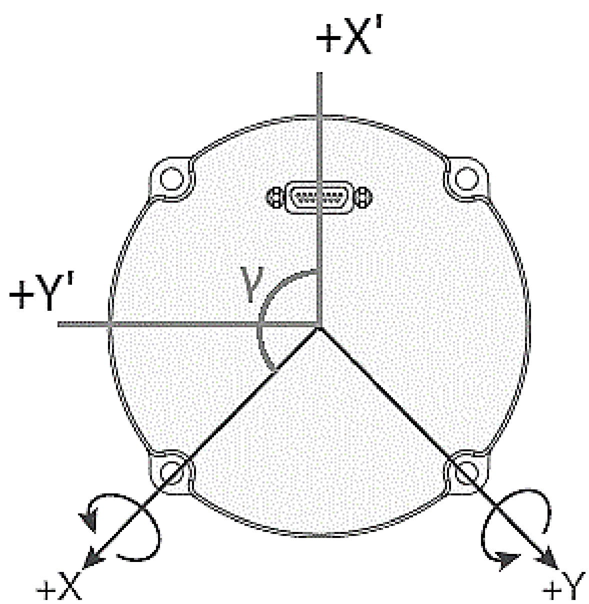
However, the reference frame does not to need to be rotated to a specific position. The angles specified in the rotation matrices below are from the sensor axis to the desired user axis. The sign of the angle is consistent with the angle of rotation, positive (counterclockwise) and negative (clockwise) as viewable from positive infinite (see Figure 9-1).

$$R_x(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}$$

$$R_y(\beta) = \begin{bmatrix} \cos(\beta) & 0 & -\sin(\beta) \\ 0 & 1 & 0 \\ \sin(\beta) & 0 & \cos(\beta) \end{bmatrix}$$

$$R_z(\gamma) = \begin{bmatrix} \cos(\gamma) & \sin(\gamma) & 0 \\ -\sin(\gamma) & \cos(\gamma) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Example: to configure the IMU to use the user axes X' and Y' in the figure below, instead of the sensor axes at the default locations of +X and +Y, use the R_z rotation matrix. The value of γ will be -135 degrees.



Example (the default axes alignment):

=AXES,1.0,0.0,0.0,0.0,1.0,0.0,0.0,0.0,1.0

8.1.3 Response

AXES,[X_0],[X_1],[X_2],[Y_0],[Y_1],[Y_2],[Z_0],[Z_1],[Z_2]
[X_{0-0}],[Y_{0-1}],[Z_{0-2}] are floating-point values typically in exponential notation.
Response to above (default) would be:

AXES,+1.000000E+00,+0.000000E+00,+0.000000E+00,+0.000000E+00,+1.000000E+00,+0.000000E+00,+0.000000E+00,+0.000000E+00,+1.000000E+00

8.2 ?axes

8.2.1 Description

This command queries the user-configured alignment axes relative to the true physical orientation of the measurement axes.

8.2.2 Usage

?AXES

8.2.3 Response

AXES,[X_0],[X_1],[X_2],[Y_0],[Y_1],[Y_2],[Z_0],[Z_1],[Z_2]
[X_{0-0}],[Y_{0-1}],[Z_{0-2}] are floating-point values typically in exponential notation and define a 3x3 rotation matrix as described in the =AXES command.

8.3 =baud

8.3.1 Description

This command sets the baud rate of the system. Not all baud rates are usable at all data rates. For instance, selecting a baud rate of 57600 with a data rate of 1000 Hz would not work, because the full output data packet cannot be transmitted in 1 ms at that baud rate. Therefore, care must be taken when using non-default data rate and baud rate combinations, or the IMU will be unreliable. (See the data rate (=DR) command and information in Section 9.)

Baud is defaulted by the Config-RST signal assertion on power on/reset or else the baud set with this command is persistent.

8.3.2 Usage

=BAUD,<9600|19200|38400|57600|115200|460800|576000|921600|4147200>

The integer value for baud is in Bd units and must be one of the acceptable values above.

8.3.3 Response

BAUD,<9600|19200|38400|57600|115200|460800|576000|921600|4147200>

Response will be at the new baud rate. Depending on software revision, the response may or may not include the new value as a parameter.

8.4 ?baud

8.4.1 Description
This command queries the baud rate of the system.

8.4.2 Usage
?BAUD

8.4.3 Response
BAUD,<9600|19200|38400|57600|115200|460800|576000|921600|4147200>
Where the value is an integer in Bd units and is one of the permitted baud rates.

8.5 ?bit

8.5.1 Description
This command is used to perform a Built-In-Test of the unit while it is running in Normal (binary) Mode. This command will return the results of internal background built-in tests that are continually being done on various pieces of hardware and software in the system to guarantee that valid readings are being made. For the most part, this reflects that internal devices are communicating appropriately and within expected times. The response will appear in the format specified by Section 5.3. The response time will vary based on system load and the selected data rate, but typically a response will be available within 100 ms of the command being issued. After a response becomes available, it will be transmitted immediately following the next data message. This is done to guarantee that the normal data message is not delayed.

The BIT results message will be appended to one of the Normal Mode data output messages following an MSYNC input signal. There may be a short delay of one or more MSYNC signals to allow the system to complete the BIT process. The user should make sure to pulse the MSYNC input signal one or more times between 90 µs and 2 s after sending the ?bit command. Failure to do so may result in bit 43 (IMU FPGA Status) of the response being set to the error state. Most users will not need to handle this as a special case, as the typical user requests data far faster than the 1/2 Hz limit. The 1775 IMU has a 90 µs hold off time from reception of one MSYNC to the next and this must also be taken into account.

8.5.2 Usage
?BIT<,2>
The optional 2 parameter specifies the alternate extended BIT test results.

8.5.3 Response
The response to ?BIT and ?BIT,2 queries are not human-readable, because the unit is operating in Normal (binary) Mode. See the sections about built-in test for details related to the response.

8.6 =config

8.6.1 Description
This command places the unit into/out of Configuration Mode. In Configuration Mode, the IMU stops sending binary data and allows the user to enter ASCII-based commands and responses to configure the unit. Configuration Mode is not stored in non-volatile/persistent memory, so the unit can be returned to Normal Mode by command or via power-on/reset.

8.6.2 Usage
=CONFIG,<0|1>
Where 0 indicates Normal Mode (Configuration Mode OFF) and 1 indicates Configuration Mode ON.

8.6.3 Response
CONFIG,1
The unit will never respond with CONFIG,0 because that would imply it is in Normal Mode.

8.7 ?config

8.7.1 Description
This command queries the Configuration Mode status.

8.7.2 Usage
?CONFIG

8.7.3 Response
CONFIG,1

8.8 =dr

8.8.1 Description

This command sets the output data rate in Hz that will occur while operating in Normal Mode and with the =MSYNC,IMU configuration. The output rate must be specified as one of the permitted values between 1 and 5000 Hz. This configuration is saved in non-volatile memory and recalled on reset/power-on. Not all data rates are usable at all baud rates. For instance, selecting a data rate of 1000 Hz with a baud rate of 57600 would not work, because the full output data packet cannot be transmitted in 1 ms at that baud rate. Therefore, care must be taken when using non-default data rate and baud rate combinations, or the IMU will be unreliable. See the baud rate (=BAUD) command and information in Section 9.

NOTE: If the currently selected filter type is either Chebyshev or Butterworth (i.e., not the Uniform Averager or a customer-defined filter) then setting the data rate has the side effect of modifying the anti-aliasing filter coefficients, so that the cutoff frequency is 1/2 of the data rate. That is, this will modify any "semi-custom" filter defined by the =FILTTYPE command.

8.8.2 Usage

=DR,<1|5|10|25|50|100|250|500|750|1000|3600|5000>

The integer value for data rate is in Hz units and must be one of the acceptable values above.

8.8.3 Response

DR, <1|5|10|25|50|100|250|500|750|1000|3600|5000>

8.9 ?dr

8.9.1 Description

This command queries the binary output data rate in Hz that will occur while operating in Normal Mode.

8.9.2 Usage

?DR

8.9.3 Response

DR,<1|5|10|25|50|100|250|500|750|1000|3600|5000>

8.10 =echo

8.10.1 Description

This command keeps a running count of how many times the echo command has been called. The counter can be incremented, set to any value, or reset to zero. This is intended to aid users establishing and testing communication links to the unit. Any set value of the echo command is not stored in non-volatile/persistent memory (the value will reset to 0 upon reset).

8.10.2 Usages

=ECHO	increment counter
=ECHO,[Value]	set counter to [Value]; response will be the same value
=ECHO,Reset	reset counter to 0; same as =ECHO,0

8.10.3 Response

ECHO,[Counter Value]
Where Counter Value is an integer that increments each time the command is used.

8.11 ?echo

The ?ECHO command is identical to the =ECHO command.

8.12 =fc20

8.12.1 Description

This command allows the user to change the final output filtering from the built-in Butterworth, Chebyshev, or Uniform Averager to a custom, user-specified filter. The user can define the filters used for accelerometer and/or gyro data individually directly through the coefficients. If the RESET parameter option is sent, this will engage the default output filters that will scale automatically with the output rate.

The final output filter is used for proper decimation (low-pass filtering and downsampling) of the internal processes to the output data rate. Normally the final filter stage is computed automatically, according to the selected data rate and filter type, and is typically either a Chebyshev or Butterworth type.

The final output filter is implemented as a four stage cascaded biquadratic (biquad) filter (8th order total). The coefficients specify the direct form 1 of the biquad having the classic transfer function in the z-domain as follows:

$$H(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

In the z-domain, z^{-n} represents a time shift of n sample periods. The b_n coefficients specify the feedforward coefficients for the new sample and its time-delayed values, the a_n coefficients specify the feedback coefficients of the time-delayed outputs, and the a_0 coefficient is normalized to a value of 1.

The IMU signal-processing will implement each of the biquad stages as the following:

$$y[n] = b_0{*}x[n] + b_1{*}x[n-1] + b_2{*}x[n-2] + a_1{*}y[n-1] + a_2{*}y[n-2]$$

Where y[n] is the output and x[n] is the input and the n-1 and n-2 terms are their time-delayed values.

When designing custom filters, the user should be conscious of anti-aliasing (Nyquist-Shannon sampling theorem) based on the output data rate. The filtering operation uses single-precision floating-point values. Installing filter coefficients that span a large numeric range (i.e., have high precision) may result in quantization errors and numerical instability. After installing custom coefficients, be sure to use the =TESTFILT command to verify the impulse response of the system is as you intended.

Both custom and built-in filters are executed at an input sample rate that is controlled by the output data rate configuration (see the =DR command description for setting the output data rate). When using a custom filter, the filter coefficients will **not** be automatically recomputed for changes to the data rate. Therefore, if the data rate is changed to a value that changes the internal gyro or accelerometer signal-processing rate, the filter should be adjusted to account for the change to the filter's input data rate. Please refer to the table below for the input sample rate for which you should design your filter's decimation factor (i.e., input rate/output rate) according to the configured final data output rate.

Table 8-1: 1775 IMU Internal Sensor Sample Rates

(All values are listed in Hz units)

Output Data Rate (Hz)	Gyro Signal-Processing Rate (Hz)	accelerometer Signal-Processing Rate (Hz)
Data Rate >= 100	20000	8312.5
100 > Data Rate >= 10	2000	831.25
Data Rate < 10	200	83.125

NOTE: When the output data rate is externally controlled by the external MSYNC signal, the unit will default automatically to use the Uniform Averager type filtering. However, the internal signal-processing rate and hence the filter's input sampling rate, is still controlled by the =DR command as shown in the table. Through the =FC20 command it is possible to change the default filter in =MSYNC,EXT mode to instead use a custom filter. The filter's frequency response should be designed to prevent aliasing at the user-driven MSYNC rate.

Coefficients for all stages must be sent even if a lower order filter is specified. Unused filter stages should be set with the all-pass coefficient values of a_1=0.0, a_2=0.0, b_0=1.0, b_1=0.0, b_2=0.0. That is, according to the equation above, y[n] = x[n].

The =FC20 command will automatically switch the filter type to <custom>. Therefore, after defining a filter with this command the unit will respond to the ?FILTTYPE query indicating that the custom filter is in use. Custom filter coefficients set with this command are stored in non-volatile memory and last until they are either reprogrammed or overridden by another configuration (e.g., =MSYNC,EXT, which defaults to using the Uniform Averager filter type or the =FILTTYPE command to set a different filter).

NOTE: Depending on software revision, there may be a limit to the number of command line characters allowed. Older software versions (1775 IMU ICB SDSP Rev. B or earlier) may limit the command line to 256 characters including the <CR> and <LF>. Due to the length of filter coefficients, the input may need to be trimmed to fit the input limit. Input with more than eight digits of precision are not required, especially if using exponential notation, since typical float precision is not valid for more than eight or nine digits.

8.12.2 Usages

=FC20,<A|G>,[A_{01}],[A_{02}],[B_{00}],[B_{01}],[B_{02}],[A_{11}],[A_{12}],[B_{10}],[B_{11}],[B_{12}],[A_{21}],[A_{22}],[B_{20}],[B_{21}],[B_{22}],[A_{31}],[A_{32}],[B_{30}],[B_{31}],[B_{32}]
=FC20,<A|G>,RESET

Values for coefficients A_{01} to B_{32} specify the biquad coefficients as single precision floating-point values for the four 2nd order stages of biquads.

8.12.3 Response

To limit the response to typical terminal emulator character limits the response is broken up into four text lines, each with <CR><LF> termination. Succeeding lines may have additional white space indentation as prefix.

Example:

FC20,[A|G],[A_{01}],[A_{02}],[B_{00}],[B_{01}],[B_{02}]
[A_{11}],[A_{12}],[B_{10}],[B_{11}],[B_{12}]
[A_{21}],[A_{22}],[B_{20}],[B_{21}],[B_{22}]
[A_{31}],[A_{32}],[B_{30}],[B_{31}],[B_{32}]

The response to the =FC20,<A|G>,RESET will be the same as above, with the default coefficients returned as values.

8.13 ?fc20

8.13.1 Description

This command queries the accelerometer or gyro filter coefficients. See the =FC20 command and examples for the typical response and filter description. This can be used to query the coefficients in use in both custom type and non-custom filters except for the Uniform Averager type.

8.13.2 Usage

?FC20,<A|G>

8.13.3 Response

See the =FC20 command response.

8.14 =filten

8.14.1 Description

This command sets whether or not the final output filter is enabled on the output data. This only applies to the final filtering prior to data output and does not change the intermediate anti-aliasing filter operation or any the other internal filtering used.

NOTE: KVH recommends that users should not operate the unit with the filter disabled as they can expect aliasing of the output data. This may especially be a problem when using the delta-velocity and delta-angle type of outputs as the, possibly noisy computed value will be applied over the entire output period. This does not change filter coefficients or filter types, so they can be disabled and enabled. Like most other commands, this configuration is saved in non-volatile memory and recalled on power-up.

8.14.2 Usage

=FILTEN,<0|1>

8.14.3 Response

FILTEN,<0|1>

8.15 ?filten

8.15.1 Description

This command queries whether the filter is enabled on the output data.

8.15.2 Usage

?FILTEN

8.15.3 Response

FILTEN,<0|1>

8.16 =filttype

8.16.1 Description

This command sets the type of low pass filter being used in the final output of data to one of the built-in types. It can be used to specify a Chebyshev filter (actually a Chebyshev type II or inverse Chebyshev), Butterworth filter, or a Uniform Averager. The command acts independently on the accelerometer and gyro filters, so each must be specified as a separate command. Command syntax usage varies according to the type of low pass filter chosen.

When specifying the Butterworth or Chebyshev types without additional parameters, the default will be used as 8th order, unity gain and the cutoff frequencies will be adjusted automatically according to the existing data rate command. In the 1775 IMU, additional optional parameters may be used to provide some semi-customization without having to fully design a custom filter. The filter coefficients will be recomputed to default (not semi-custom) conditions if the data rate is subsequently changed with the =DR command. Therefore, when using the semi-custom filter options, the data rate should be set as desired prior to the =FILTTYPE command.

Selection of the Uniform Averager type low-pass filter results in accumulation of data followed by averaging over the output period (i.e., it is **not** a moving average). This filter type is automatically selected as the default when the unit is configured for external output rate control (=MSYNC,EXT command) operation. The period of average will be based on the ratio of input sampling rate to output sampling rate where input sampling rate is controlled by the data rate command according to the sample rate in Table 8-1.

After setting filter type for Butterworth or Chebyshev, the ?FC20 command can be used to read back the coefficients in use. Also, the =TESTFILT command can be used to get the impulse response. This is not true for the Uniform Averager type since it does not affect the biquad stage coefficients.

Some optional parameters, if invalid, may result in a warning about usage and others may result in undefined behavior. For example, cutoff frequencies above the Nyquist ratio of a filter’s input sample rate (output cutoff frequency/internal sample rate >= 0.5) may be accepted. However, in this case, the filter coefficients should result in an all pass filter without any warning or error (see the =FC20 command for table of internal sample rates).

NOTE: As with all commands, users should not assume that the existing behavior of undefined or out of range parameters will be the same in future software versions.

There is no way to specify the filter type as a true custom eight-order filter with this command. However, simply using the =FC20 command with user-defined filter coefficients (see the =FC command description for details) automatically switches the filter type to custom, so the ?FILTTYPE query may return type custom.

The default output filtering can be restored using the =FC20 command’s reset parameter or by using the CHEBY keyword type without any additional parameters.

Changing the Master Synchronization Input to external (=MSYNC,EXT) will automatically change the filter type to the Uniform Averager type. This filter type will remain even after changing the Master Synchronization Input back to =MSYNC,IMU type later on. When using the external MSYNC mode, if the user wants a different filter than the Averager type they must configure it with the =FILTTYPE command **after** issuing the =MSYNC,EXT command.

8.16.2 Usage

=FILTTYPE,<A|G>,<CHEBY|BUTTER|AVE><,additional parameters>

Uniform Averager USAGE: =FILTTYPE,<A|G>,AVE
There are no optional or additional parameters for the Averager. As with other final output filters, use of the data rate (=DR) command may affect the averaging filter input rate by changing the internal sampling rates. When using the Averager filter and external output request, KVH recommends setting the data rate configuration to 1000 Hz, even if the user does not expect to drive the output request at that rate, to use the fastest internal averaging. For IMU-generated data output timing, the averaging period will automatically adjust with the chosen data rate.

Butterworth USAGE: =FILTTYPE,<A|G>,BUTTER<,N,FCUTOFF>
The N and FCUTOFF parameters are optional and, if not used, then the default is 8^{th} order and the cutoff frequency is at 1/2 of the configured data rate. If optional parameters are used, then both parameters must be specified and the desired data rate should be configured prior.

Optional parameters:

- N is filter order; integer with range 1 to 8
- FCUTOFF is filter cutoff frequency in Hz; floating-point value, range is 0 to 2500 Hz. KVH recommends setting this to less than 1/2 the expected data output rate, although values up to 1/2 the internal sampling rate are accepted. That is, the 2500 Hz or lower value would be used with at the maximum 5000 Hz data rate.

Chebyshev USAGE: =FILTTYPE,<A|G>,CHEBY<,N,GSTOP,FSTOP>
The Chebyshev (type II) is the default final output filter. The N, GSTOP and FSTOP parameters are optional and if not used, then the default is 8th order with 0.01 stop gain (-40dB) and the stop band frequency will be 0.545*data rate. If optional parameters are used, then both parameters must be specified and the desired data rate should be configured prior.

Optional parameters:

- N is filter order; integer with range 1 to 8
- GSTOP is stop band gain as a unitless ratio; floating-point value, typical range is between about 0.1 to 0.001. To convert from dB units: $GSTOP = 10^{(dB/20)}$ or according to Table 8-2 below:

Table 8-2: GSTOP Gains

GSTOP (Out/in)	dB gain
0.1	-20 dB
0.01	-40 dB
0.001	-60 dB

- FSTOP is stop band frequency in Hz units; floating-point value, range is 0 to about 3000 Hz

8.16.3 Response
FILTTYPE,<A|G>,<CHEBY|BUTTER|AVE>
Note: the unit will not respond back optional parameters for Butterworth or Chebyshev types.

8.16.4 Examples and Further Information
Examples for =FILTYPE command:

Table 8-3: FILTYPE Commands and Responses

Commands (CR/LF not shown)	Response	Final Output Filter Description
=filttype,a,butter	FILTTYPE,A,BUTTER	Default Butterworth applied to accelerometers, cutoff at 0.5 data rate
=filttype,a,butter,4,125.25	FILTTYPE,A,BUTTER,4,125.25 (* see errata note)	Semi-custom Butterworth, 4-order with 125.25 Hz cutoff frequency applied to accelerometers
=filttype,g,ave	FILTTYPE,G,AVE	Uniform Averager applied to gyros
=filttype,g,cheby	FILTTYPE,G,CHEBY	Default Chebyshev type II applied to gyros
=filttype,g,cheby,8,0.01,545	FILTTYPE,G,CHEBY,8,0.01,545 (* see errata note)	Chebyshev applied to gyros; this is the same as default for a data rate of 1000 Hz
* ERRATA NOTE: for FILTTYPE command, spaces instead of commas after the BUTTER or CHEBY keywords may appear on early firmware versions.		

Table 8-4 below is **not** the recommended steps for programming, but can be followed for discussion on how the unit behaves. For an understanding of the interaction of certain commands follow along the steps below, in sequence.

Table 8-4: 1775 IMU Command Behavior

Commands (CR/LF not shown)	Responses	Discussion and Unit Status
=config,1	CONFIG,1	The user enters Configuration Mode; unit stops output of binary data.
=msync,ext	MSYNC,EXT	The user sets unit to external MSYNC mode; unit will now configure to output one set of data for each external MSYNC input. Output filtering of gyro and accelerometer data is automatically set to Uniform Averager type filtering. There is no data output yet because the unit is still in configuration mode.
?filttype,a	FILTTYPE,A,AVE	Confirms the Averager type is active for accelerometer data.
?filttype,g	FILTTYPE,G,AVE	Confirms the Averager type is active for gyro data.
=filttype,g,butter	FILTTYPE,G,BUTTER	Gyro data filter reconfigured from Averager to the default Butterworth 8th order and at 1/2 the configured data rate (whatever was set previously).
=dr,1000	DR,1000	The user sets data rate to 1000 Hz; gyro filter recalculated to Butterworth, 8th order at 500 Hz cutoff. Still in external MSYNC mode with output driven by user supplied signal.
=filttype,g,butter,4,250	FILTTYPE,G,BUTTER,4,250 (* see errata note)	Gyro data filter set to Butterworth, 4th order at 250 Hz cutoff; Data rate remains at 1000 Hz and output is still driven by external MSYNC.
=dr,100	DR,100	The user sets data rate to 100 Hz; gyro filter recalculated to Butterworth, 8th order at 50 Hz cutoff. Accelerometer filter is still the Averager type.

Commands (CR/LF not shown)	Responses	Discussion and Unit Status
=filttype,g,butter,6,500	FILTTYPE,G,BUTTER,6,500 (* see errata note)	Gyro data filter set to Butterworth, 6th order at 500 Hz cutoff; Data rate is still 100 Hz and driven by external MSYNC. If internal IMU timed output was used, then the cutoff frequency is above the data rate of 100 Hz, so aliasing will occur in the output data. However, since 500 Hz is below, the internal sampling rate (filter input rate) it is valid.
=filttype,g,butter,6,20000	FILTTYPE,G,BUTTER,6,20000 (* see errata note)	Gyro data filter set to an invalid configuration since the cutoff frequency is at or above the internal sampling rate. Unit will configure an all pass filter and gyro data output is unfiltered.
=dr,100	DR,100	The user resets data rate to 100 Hz (data rate is unchanged from prior command); gyro filter recalculated to Butterworth, 8th order at 50 Hz cutoff.
=config,0	Unit will begin output of binary data; one set of data for each external MSYNC signal seen.	The user leaves Configuration Mode; unit will now output one data set for each external MSYNC signal, gyro data has an 8th order Butterworth filter at 50 Hz cutoff and the accelerometer data is using the Uniform Averager.
* ERRATA NOTE: for FILTTYPE command, spaces instead of commas after the BUTTER or CHEBY keywords may appear on early firmware versions.		

8.17 ?filttype

8.17.1 Description
This command queries the type of filter being used; it acts independently on the accelerometer and gyro filters, so each must be specified as a separate query. This returns custom type if the =FC20 command was used to define the coefficients. In the 1775 IMU, if a semi-custom filter configuration is being used this does not report the special configuration.

8.17.2 Usage
?FILTTYPE,<A|G>

8.17.3 Response
FILTTYPE,<A|G>,<CHEBY|BUTTER|AVE|custom>

Example.
?FILTTYPE,A
FILTTYPE,A,CHEBY

8.18 =help

8.18.1 Description
This command displays a list of implemented commands.

8.18.2 Usages
=help
=help[,command]

8.18.3 Response
When using the help command without any parameters, the output lists all of the available commands and their descriptions.

8.19 ?help
?HELP is identical to =HELP.

8.20 ?is

8.20.1 Description
This command returns the main serial number of the unit.

8.20.2 Usage
?IS

8.20.3 Response
IS,[Serial Number]
Serial number is a text string, typically with a numeric value.

8.21 =linfmt

8.21.1 Description

This command sets the linear (accelerometer) data format used for output in Normal Mode. It can be set to either acceleration in g's (default) or delta velocity. If setting to delta velocity, be sure to set the units using the =LINUNITS command.

8.21.2 Usage

=LINFMT,<ACCEL|DELTA|RESET>

8.21.3 Response

LINFMT,<ACCEL|DELTA|RESET>

8.22 ?linfmt

8.22.1 Description

This command query returns the linear (accelerometer) data output format used in Normal Mode, either acceleration in g's or delta velocity.

8.22.2 Usage

?LINFMT

8.22.3 Response

LINFMT,<ACCEL|DELTA>

8.23 =linunits

8.23.1 Description

This command sets the linear (accelerometer) data output units. Only applies if the linear data output format is **not** set to acceleration in g's, which is the default selection. See the =LINFMT command for details on changing the linear data output format.

As an example, if the format is set to delta velocity and you select the output units to be meters (default), the data you receive will be measured in delta meters per second. If you change the units to feet, you will receive data in delta feet per second.

8.23.2 Usage

=LINUNITS,<METERS|FEET|RESET>

8.23.3 Response

LINUNITS,<METERS|FEET|RESET>

8.24 ?linunits

8.24.1 Description

This command query returns the linear (accelerometer) data output units. This setting only has meaning if the linear data output format is changed from the default value of acceleration in g's. See the =LINFMT command for details.

8.24.2 Usage

?LINUNITS

8.24.3 Response

LINUNITS,<METERS|FEET>

8.25 ?logs

8.25.1 Description

This is a diagnostic command that gets the BIT status logs stored in flash. A user might be requested to do this as part of service support. (See Table 5-12 through Table 5-19 for details on logged bit statuses.)

8.25.2 Usage

?LOGS

8.25.3 Response

```
Start of log entries!
Log 1:
 Source - Start up
 Format - BIT Status
 Data - 0x7F7F7F7F7F7F7F7F
Log 2:
 Source - ?BIT
 Format - BIT Status
 Data - 0x7F7F7F7F7F7F7F7F
End of log entries!
```

8.26 =msync

8.26.1 Description

This command configures the system's data output request method for Normal Mode. It can be set to use an internally generated periodic clock in IMU mode, or to use the external interface MSYNC signal in EXT mode. (See Section 10.3 for important information regarding the use of the Master Synchronization Input.) This command is related to the =DR and =OUTPUTFMT commands and define the Normal Mode behavior.

8.26.2 Usage

=MSYNC,<EXT|IMU>

IMU mode generates the Normal Mode data output messages based on the data rate defined by the =DR command. EXT mode uses the Master Synchronization Input signal on the interface connector to request data output at a user-driven rate. The user-driven output rate can be either periodic or aperiodic. Setting this to EXT will automatically engage the Uniform Averager type output filtering on both the accelerometer and gyro data (see the =FILTTYPE command). It will not change the filter enable configuration however.

8.26.3 Response

MSYNC,<EXT|IMU>

8.27 ?msync

8.27.1 Description

This command queries whether the system is expecting timing synchronization via the Master Synchronization Input or if it internally controls the output timing. (See Section 10.3 for details about the Master Synchronization Input.)

8.27.2 Usage

?MSYNC

8.27.3 Response

MSYNC,<EXT|IMU>

8.28 =outputfmt

8.28.1 Description

This command configures the output format of the binary data message used in the Normal Mode. The value is stored in non-volatile memory.

8.28.2 Usage

=OUTPUTFMT,<A|B|C>

8.28.3 Response

OUTPUTFMT,<A|B|C>

8.29 ?outputfmt

8.29.1 Description

The command query responds with the currently configured output format of the binary data used in the Normal Mode.

8.29.2 Usage

?OUTPUTFMT

8.29.3 Response

OUTPUTFMT,<A|B|C>

8.30 =restart

8.30.1 Description

This command restarts the system. This is equivalent to asserting power to the External Reset input on the Micro-D interface connector. It should result in the system reboot of programmable devices and configurations. It is similar to a power cycle in that certain parts of the system will experience a hardware reset signal. However, not all devices (e.g., power supplies) will be reset.

8.30.2 Usage

=RESTART

8.30.3 Response

The system does not respond specifically to the RESTART command. It should result in the unit output of Normal Mode data in the configured format.

8.31 =rotfmt

8.31.1 Description

This command configures the rotational (gyro) data format that is output in Normal Mode to either delta angle or rate of rotation. The RESET parameter restores the factory default configuration (see Section 9).

8.31.2 Usage

=ROTFMT,<DELTA|RATE|RESET>

8.31.3 Response

ROTFMT,<DELTA|RATE|RESET>

8.32 ?rotfmt

8.32.1 Description

This command queries the rotational (gyro) data format being output in Normal Mode, either delta angle or rate of rotation.

8.32.2 Usage

?ROTFMT

8.32.3 Response

ROTFMT,<DELTA|RATE>

8.33 =rotunits

8.33.1 Description

This command sets the rotational (gyro) data units being output in Normal Mode, either degrees or radians. If ROTFMT command was set for DELTA, then this will set units for degrees or radians. If ROTFMT is RATE, then this will set units for degrees/sec or radians/sec. The RESET parameter selects the factory default configuration (see Section 9).

8.33.2 Usage

=ROTUNITS,<DEG|RAD|RESET>

8.33.3 Response

ROTUNITS,<DEG|RAD|RESET>

8.34 ?rotunits

8.34.1 Description

This command queries the rotational (gyro) units being output in Normal Mode, either degrees or radians.

8.34.2 Usage

?ROTUNITS

8.34.3 Response

ROTUNITS,<DEG|RAD>

8.35 =rstcfg

8.35.1 Description

This command resets all configuration settings back to the factory defaults. The settings include the output data rate, filter settings, output units, axes, etc. (See Section 10 for the settings that are reset to defaults.) This is similar to asserting the Configuration Reset signal on the Micro-D Interface.

Errata Note: in Rev. B software and earlier, this command also defaults the serial communications baud rate. If necessary, users will have to adjust host communications to the default baud and then reprogram the baud back to the desired value after issuing this command.

8.35.2 Usage

=RSTCFG

8.35.3 Response

RSTCFG

8.36 ?temp

8.36.1 Description

This command query returns the main temperature sensor of the system as an integer string. The units returned depend on the configuration defined by the =TEMPUNITS command.

8.36.2 Usage

? TEMP

8.36.3 Response

TEMP,[Temperature Value]

Example, temperature in degrees C for 45^{o} C:
TEMP,45

Example, temperature in 100ths of degrees C for 45.02^{o} C:
TEMP,4502

8.37 =tempunits

8.37.1 Description

This command sets the temperature units used when the device outputs in Normal Mode, or when given the ?TEMP command. The user can use the C_100 and F_100 to increase resolution to two decimal places. The units will still report a whole number integer and the user must divide by 100 to get the decimal equivalent. The configuration is saved in non-volatile memory.

8.37.2 Usage

=TEMPUNITS,<C|F|C_100|F_100>

8.37.3 Response

TEMPUNITS,<C|F|C_100|F_100>

8.38 ?tempunits

8.38.1 Description

This command queries the temperature units being reported, either degrees C or F or their corresponding 100ths of degree units.

8.38.2 Usage

?TEMPUNITS

8.38.3 Response

TEMPUNITS,<C|F|C_100|F_100>

8.39 =testfilt

8.39.1 Description

This command tests the filter that is currently implemented for the accelerometers and gyros. It is intended for verification of custom filters, but can be used with the built-in Chebyshev and Butterworth filter types.

This command does **not** apply for the Uniform Averager type filter or for when the filter is disabled. The output results may be undefined in such cases.

When run, this zeroes the state variables, then applies a unit impulse to the configured filter and outputs the results of the first 2^{16} (65536) output values of each filter. The user can then capture the results, which can be run through an FFT using third party analysis software to verify that the magnitude and phase response of the filter matches the desired implementation.

Depending on the configured baud, the response can take several minutes to return all the values for each of the accelerometer and gyro output filters. The numeric values returned are ASCII encoded strings of floating-point values and may be in decimal or exponential notation.

Each numeric value represents one sample period at the internal sampling rate of the particular filter. The internal sampling rate (i.e., the filter input rate) is dependent on the configured data rate. Please refer to the sample rate table in the =DR command for the input sample rates relation to the data rate. For example, at 1 KHz data rate and for the accelerometer filters, the sample rate is 8.3125 KHz, so each sample represents a time period of (1.0 / 8312.5) Hz or approximately 0.1203 ms and the command reports up to 7.88 secs of impulse response time.

In Rev. C software and later, the response will indicate the number of samples and the sample period that can be used to compute the FFT of the filter response.

8.39.2 Usage

=TESTFILT
=TESTFILT,<A|G>,<SAMPLES>

A for accel; G for gyro, optional argument to get only the specific filter response
SAMPLES is an optional argument as an integer value from 2 to 65536 (must be preceded by A or G option) to request less than default number of samples.

8.39.3 Response

Example 1: for command =testfilt
TESTFILT
Testing Accel filter impulse response; 65536 samples
(Accel sample period is 0.1203 ms)
+0.00989369862
+0.01022341289
…
+0.00000000000
+0.00000000000
+0.00000000000
Accel filter test complete
Testing Gyro filter impulse response; 65536 samples
(Gyro sample period is 0.0500 ms)
+0.00910380296
+0.00664431229
+0.01628635451
…
+0.00000000000
+0.00000000000
Gyro filter test complete

Example 2: for command =testfilt,g,20
TESTFILT
Testing Gyro filter impulse response; 20 samples
(Gyro sample period is 0.0500 ms)
+0.00819911063

-0.00015651807
+0.00477615930
+0.00683800876
+0.00767558068
+0.00821539760
+0.00892141461
+0.00997492671
+0.01139687002
+0.01312804222
+0.01507931948
+0.01716038585
+0.01929408312
+0.02142292261
+0.02350741625
+0.02552491426
+0.02746337652
+0.02931761742
+0.03108656406
+0.03276658058

8.40 ?testfilt

?TESTFILT is identical to =TESTFILT. See the appropriate section for details.

8.41 ?volt

8.41.1 Description

This command is a diagnostic query that returns the available primary supply voltages on the system. It might be run at the request of sales/service and is not typically needed by a user.

8.41.2 Usage

?VOLT

8.41.3 Response

VOLT,[1 Volt],[3 Volt],[5 Volt]

[1 Volt] indicates the voltage on an internal 1.2V supply.
[3 Volt] indicates the voltage on an internal 3.3V supply.
[5 Volt] indicates the voltage on an internal 5.0V supply.

All values are returns as ASCII strings representing float values.

Example response with approximate typical values:
VOLT,1.187,3.307,4.974

8.42 ?ws

8.42.1 Description

This is a diagnostic command to query the software versions of the various internal programmable devices. It is intended for software update utility programs to determine existing versions for field firmware update purposes. Normally users do not need to operate this command. Software versions relate to internal programmable devices including DSPs and FPGAs.

8.42.2 Usage

?ws

8.42.3 Response

1775 IMU
ICB DSP Rev [ICB DSP Revision Letter] Version: [ICB DSP Version Number]
ICB FPGA Rev: [ICB FPGA Hexadecimal Version Number]
GCB DSP Rev [GCB DSP Revision Letter] Version: [GCB DSP Version Number]
GCB FPGA Rev: [GCB FPGA Revision Letter]

9 Configuration Options

The major configuration parameters are summarized in Table 9-1. All options are configurable using the commands in Section 8. Axes of rotation and linear motion are shown in Figure 9-1.

Table 9-1: Configuration Options Summary

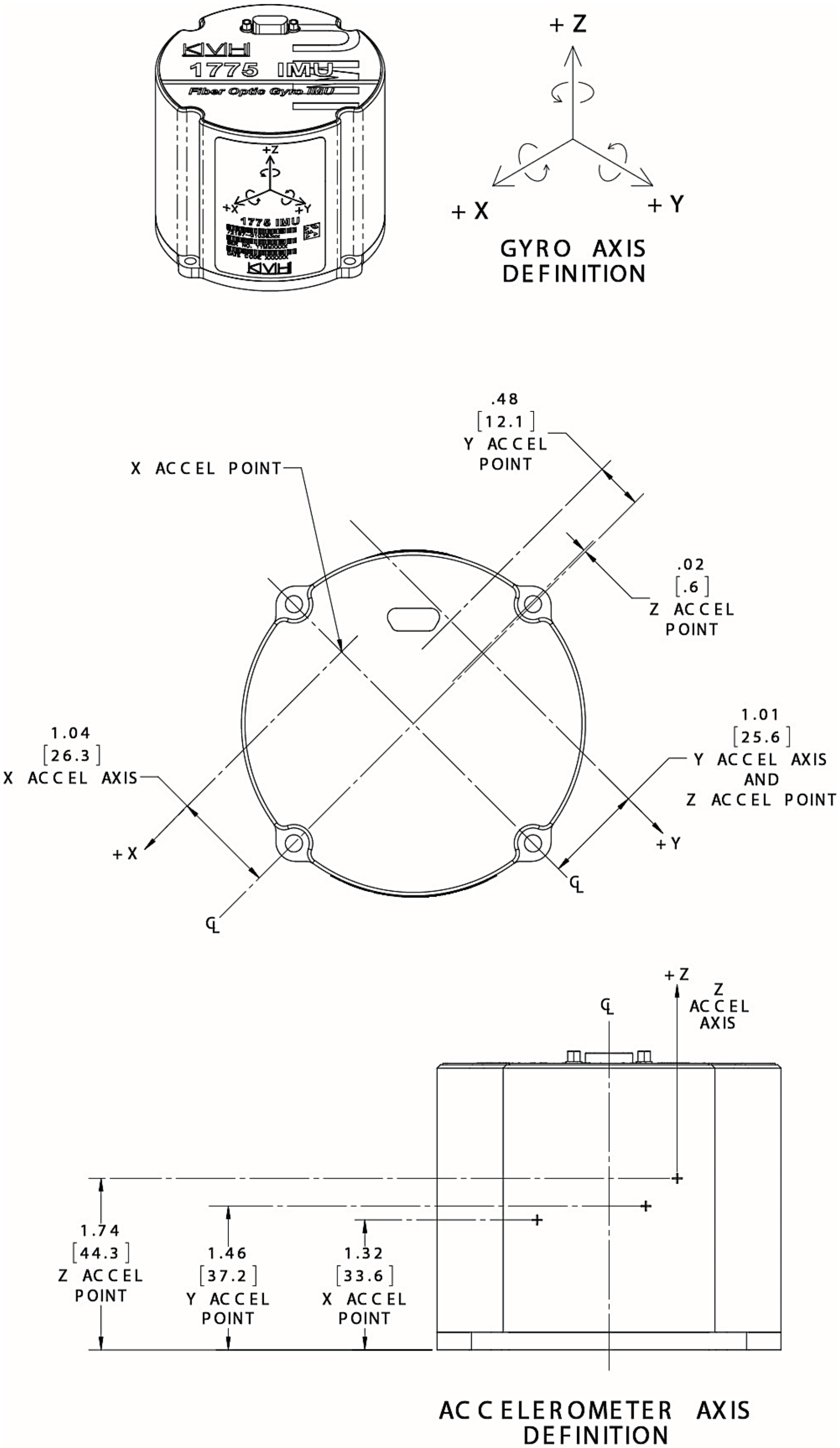
Parameter	Options	Default Value	Units	Configuration Command
Baud rate[(1)]	9600, 19200, 38400, 57600, 115200, 460800, 576000, 921600, 4147200	921600	Bd (same as bits/sec)	=BAUD to set ?BAUD to query
Data rate[(2)]	1, 5, 10, 25, 50, 100, 250, 500, 750, 1000, 3600, 5000	1000	Hz	=DR to set ?DR to query
Output Format	A, B, C	A	N/A	=OUTPUTFMT to set ?OUTPUTFMT to query
Temperature Units	ºC, ºF, ºC_100, ºF_100	ºC	N/A	=TEMPUNITS to set ?TEMPUNITS to query
Angular Units	Radians, degrees	Radians	N/A	=ROTUNITS to set ?ROTUNITS to query
Rotational data (gyro) format	Rate of rotation (radians/sec or degrees/sec) delta angle[(3)] (radians or degrees)	Delta angle	Varies by option	=ROTFMT to set ?ROTFMT to query
X, Y, Z axis definitions[(4)]	Rotation matrix[(5)] from reference axes shown in Figure 9-1	1 0 0 0 1 0 0 0 1	N/A	=AXES to set ?AXES to query
Linear Units	Meters, Feet	Meters	N/A	=LINUNITS to set ?LINUNITS to query
Linear data (accelerometer) format	accelerometer, Delta	Acceleration in g (g-force) units	Acceleration in g or delta-velocity	=LINFMT to set ?LINFMT to query
Output filter enable/disable	Enabled (1) disabled (0)	Enabled	N/A	=FILTEN to set ?FILTEN to query
Output filter type	Chebyshev, Butterworth, Uniform Averager, customer defined 8th order filter	Chebyshev (type II) filter	N/A	=FILTTYPE to set ?FILTTYPE to query
Output filter coefficients	Infinitely configurable 8th order filter coefficients	Chebyshev (type II) filter	N/A	=FC20 to set ?FC20 to query
Output Request synchronization	Internal clock, External request[(6)]	Internal clock (IMU mode)	N/A	=MSYNC to set ?MSYNC to query

Parameter	Options	Default Value	Units	Configuration Command

Table 9-1 Notes:

1) Reducing the baud rate from the default increases the time duration of the data being output from the unit. If the baud rate is decreased by too much, it may result in an inability to achieve the set data rate. (Refer to Section 9.1 for recommended baud rate/data rate limits.) Baud rate will set to default for Config-RST-IN signal assertion. Baud rate will not change for RSTCFG command.
2) The data rate command (=DR) directly controls the data output rate when the MSYNC is configured for IMU, which is the default. If the external MSYNC signal is configured (=MSYNC,EXT), any data output rate from 1 to 5000 Hz is available and controlled by user request. However, the user is responsible for ensuring the output filters are appropriately set. See the entry named “Output Request Synchronization” in this table.
3) Delta angle differs from rate of rotation in that it uses the rate of rotation over the time since the last data output to compute the angular displacement (it integrates the rate of rotation over time).
4) The three axes of rotation are coincident with the linear acceleration axes. Positive rotation is a counterclockwise rotation about an axis when viewed from $+\infty$ along that axis (see Figure 9.1). Linear acceleration polarity is such that the IMU will report +1 G due to Earth gravity when its positive axis is up. The rotation matrix only applies to gyro and accelerometer data. Magnetic data in output Format C is not affected.
5) Any matrix will be accepted by the unit. It is up to the user to ensure that the matrix is a valid rotation matrix and does not result in any scaling issues (e.g., entering =axes,4,0,0,0,1,0,0,0,1 would make the X axis measurements four times as large as they should be). This is not intended as a means of changing scale factors.
6) The MSYNC,EXT mode will automatically select the Uniform Averager type filtering. Interaction with the =DR and filtering commands is command-order specific. The user should refer to appropriate sections to describe these interactions.

Figure 9-1: Axis Definitions Relative to the Unit



9.1 Configuration Limits

Some configuration options associated with data rate and communications baud should not be set beyond certain limits.

Table 9-2: Maximum Data Rates At Given Baud Rates

Baud Rate (Bd)	Maximum Data Rate (Hz)
9600	10
19200	25
38400	50
57600	100
115200	100
460800	500
576000	750
921600	1000
4147200	5000

10 Control Signal Inputs

10.1 Config-RST-In (Configuration Reset) Input

The 1775 IMU has a differential input labeled Config-RST-In+/Config-RST-In- on the external connector that can be used to perform a configuration reset of the system. This input is only monitored at startup and is ignored during normal operation. These pins may be left disconnected at the unit interface connector unless use is desired.

To reset all configuration settings (including baud) to their factory defaults, assert a positive RS-422 compliant voltage from the Config-RST-In+ pin to the Config-RST-In- pin before restarting the unit. The unit may be restarted by one of the following: applying power, applying external reset, or sending the =RESTART command. If used, the configuration reset condition should be held until the unit starts outputting Normal Mode data. This will default unit configuration similar to the =RSTCFG command. The differences are that =RSTCFG command does not require an actual unit restart.

The default configuration parameters are listed in Section 9.1.

10.2 EXT-RST (External Reset) Input

The 1775 IMU has a differential input labeled EXT-RST+/EXT-RST- on the external connector that can be used to perform a hardware reset (cold start) of the system. Asserting a positive RS-422 compliant voltage from the EXT-RST+ pin to the EXT-RST- pin at any time will result in a reset. These pins may be left disconnected at the unit interface connector unless reset is desired.

External reset operation is similar to a power-cycle of the power inputs in that certain parts of the system will experience a hardware reset signal. It should result in the system reboot of programmable devices and configurations. However, not all devices (e.g., power supplies) will be reset.

A unit in Configuration Mode (=CONFIG,1 command) will restart to the configured Normal Mode. Other configuration parameters will be recalled from non-volatile memory.

10.3 MSYNC (Master Synchronization) Input

By default, the 1775 IMU will internally self-time the output message rate according to the configuration of the =DR command.

The 1775 IMU provides an optional RS-422 differential input (named MSYNC+/MSYNC-) that allows the user to request data output within the limits of the unit. When configured for external MSYNC mode, asserting a positive RS-422 compliant voltage from the MSYNC+ pin to the MSYNC- pin will result in the unit sending out a data message in the configured format. These pins may be left disconnected at the unit interface connector unless external MSYNC is desired. The configuration of the internal or external data output requests is controlled by the =MSYNC command.

Internal to the IMU, the MSYNC signal, whether internally or externally generated, will be captured and will cause the IMU to sample its sensor data and prepare and transmit a data message (see Figure 10-1). MSYNC is shown in the diagram as a single signal and assumes that MSYNC+ and MSYNC- operate together as a differential pair to define the active (high) or deasserted (low) state.

Figure 10-1: MSYNC Signals

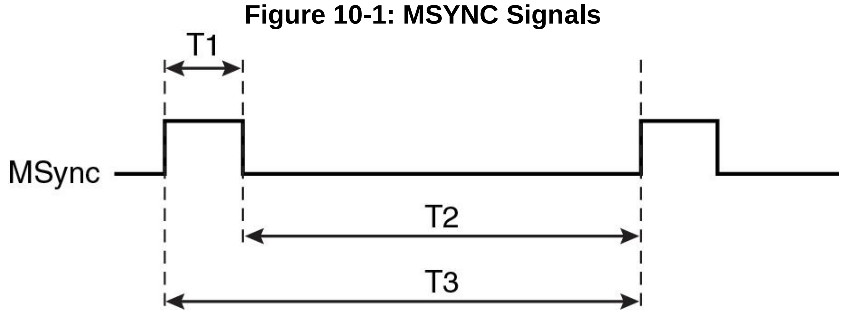


Table 10-1: MSYNC Timing Parameters

Timing Parameter	Description	Value
T1	MSYNC active	MSYNC+ high and MSYNC- low ≥30 µs; Recommended high time is less than approximately 90 µs.
T2	MSYNC deasserted	MSYNC+ low and MSYNC- high ≥30 µs
T3	Period between rising edges	0.2-2000 ms; *Note: MSYNC might be sent faster than 200us when using the BIT function, but in no cases should it be sent faster than 100us or it may be ignored.*

On the 1775 IMU, the external MSYNC input has a short debounce protection time on its active (rising MSYNC+/ falling MSYNC-) edge of approximately 0.5 µs. This is followed by a hold-off time of approximately 92 µs before it will recognize another active edge. This hold-off time is to prevent retriggering the output, possibly from noise on the interface cable. There is also a short (~ 1 µs) debounce protection time on its falling edge. Noise such as signal reflections or crosstalk of the external wiring should be avoided by careful design of the external wiring harness. However, setting the timing of the MSYNC input duty cycle such that the falling edge of external MSYNC falls within the hold-off period can help ensure proper MSYNC operation.

When selecting the external MSYNC signal as the output data request source, the system will automatically switch the filter to use the Uniform Averager type. This will override any previous filter type selection the user has configured (including a custom filter). It will not, however, change the filter enable/disable configuration. The change to Uniform Averager is done so the user is not forced to provide a regular periodic clock, but rather use the Master Synchronization Input as an arbitrary aperiodic request for data. You may override this and install any filter you choose. You can select from a predefined or custom eighth-order filter by using a combination of the =DR, =FILTTYPE, =FC20, and =FILTEN commands. These must be sent **AFTER** the =MSYNC,EXT command.

NOTE: The unit assumes that the user will always want data at a frequency greater than 1/2 Hz. If a rising edge of the MSYNC signal is not detected within two seconds, the unit will consider this a fault condition and will output data at the two-second interval. When the next MSYNC signal rising edge is detected, the unit will resume synchronized output. This may be convenient as an indication that the user's MSYNC signal was not recognized by the unit (e.g., perhaps due to cabling or other error condition).

10.3.1 Example 1

The user wishes to use a Uniform Averager with MSYNC. The Averager is the default filter when using MSYNC, so no additional configuration is needed.

```
=config,1
=msync,ext
=config,0
```

10.3.2 Example 2

The user wishes to enable MSYNC while turning off the filters entirely (i.e., user does not want the IMU to implement either a Uniform Averager, or any kind of 8th order anti-aliasing filter; this is not recommended by KVH due to aliasing of the output data). The =FILTEN configuration is not changed automatically by the =MSYNC command, so this could be done in reverse order or at some time previously. Send the following commands to the unit:

```
=config,1
=msync,ext
=filten,0
=config,0
```

10.3.3 Example 3

The user wishes to enable MSYNC and wants to have the IMU implement a Butterworth anti-aliasing filter with a 3dB cutoff of 50 Hz. Send the following commands to the unit:

Correct:

=config,1
=msync,ext
=dr,100
=filttype,a,butter
=filttype,g,butter
=config,0

Incorrect

=config,1
=filttype,a,butter
=filttype,g,butter
=msync,ext
=dr,100
=config,0

NOTE: If you were to send the =FILTTYPE,BUTTER command before =MSYNC,EXT, the unit would not be configured with a Butterworth filter. This is because it automatically switches to the Uniform Averager type when Master Synchronization is enabled, even if you have previously configured the filter type.

10.3.4 Example 4

The user wishes to enable external MSYNC and implement a custom filter. Enter the desired coefficients using the =FC20 command. The internal signal-processing rate is determined by the =DR command. Enter the following commands (the filter coefficients are completely made up in this example):

=config,1
=msync,ext
=dr,1000
=fc20,a,0.1,0.2,0.3,0.4,0.5,0.1,0.2,0.3,0.4,0.5,0.1,0.2,0.3,0.4,0.5,0.1,0.2,0.3,0.4,0.5
=fc20,g,0.4,0.3,0.2,0.1,0.0,0.4,0.3,0.2,0.1,0.0,0.4,0.3,0.2,0.1,0.0,0.4,0.3,0.2,0.1,0.0
=config,0

Just as in Example 3, you must send the =MSYNC,EXT command **before** changing the filter type. Also, you must send the =DR command **before** setting the custom filter.

11 Time of Validity Output (TOV)

11.1 TOV Summary

The 1775 IMU provides an optional RS-422 differential output on the external connector (named TOV-OUT+/TOV-OUT-) to indicate the time at which the data being output on the serial port can be considered to be relevant. This output is only relevant when the unit is in Normal Mode (i.e., unit is set to output binary data on the serial port). When the unit is not in Normal Mode (e.g., it is in Configuration Mode) the TOV indication should be ignored.

When used, KVH recommends that this signal be connected to a properly terminated RS-422 receiver to prevent signal reflections and crosstalk. If not used, it may be left unconnected.

The TOV signal can be used as an indication that output of a data message is going to occur. It can also be used by a system to timestamp the subsequent data message as it will be very close in time to the IMU's sampling of its rotational and linear sensors (refer to Table 11-1).

The behavior of the TOV signal depends on whether the unit is generating its own (internal) timing (default or =MSYNC,IMU) or if it is relying upon the user-driven timing associated with the Master Synchronization Input (see Section 11.3 for details).

11.2 TOV Timing

TOV is shown in the diagram as a single signal and assumes that TOV+ and TOV- operate together as a differential pair to define the active (high) or deasserted (low) state.

Figure 11-1: TOV Output Timing Relative to Serial port Activity

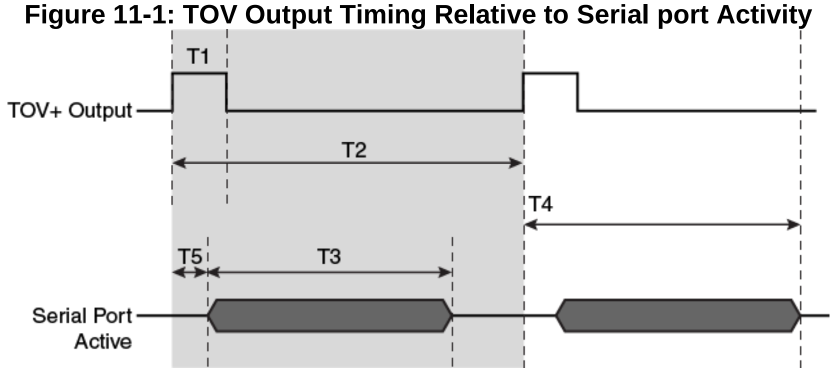


Table 11-1: TOV Timing Parameters

Timing Parameter	Description	Value
T1	TOV High	MSYNC,IMU: high time is 10% of the TOV period (for example, at a default baud rate of 1,000 Hz, the T0 high time will be 100 µs for internal clock mode) MSYNC,EXT: high time is approximately the same as the external MSYNC signal active time
T2	TOV period	MSYNC,IMU: Period is determined by the output data rate (for example, at default data rate of 1,000 Hz, T2 = 1000 µs) MSYNC,EXT: period reflects the external MSYNC signal
T3	Duration of the serial port output	Depends on output format and baud rate; approximately equal to the number of characters output multiplied by the number of bits per character (10) divided by the baud rate (for example, Format A at default baud rate of 921600 Bd, T3 is approximately 390 µs)
T4	Time between rising edge of TOV-Out and the end of data transmission	<500 µs (at default baud rate of 921600 Bd)
T5	Time between start of TOV and the start of T2	typ 30 to 100 µs

11.3 TOV with Internal MSYNC Mode

When the IMU is providing its own data output requests based on its internal source's preconfigured rate, the unit outputs the differential TOV signal with a 10% duty cycle at the same frequency as the data output (see the diagram in Figure 11-1 and the parameters in Table 11-1).

11.4 TOV with External MSYNC Active

When the external Master Synchronization Input is configured, the IMU will simply buffer (repeat) the MSYNC signal back out to the TOV signal. Therefore, the timing should closely mirror the external MSYNC signal.

12 Data Output Signal-Processing

During Normal Mode, operation the IMU Controller Board (ICB) needs to process data from its sensor sub-systems and prepare it for output to the user system. The ICB is continually sampling its various sensor data sub-systems and is checking for user requests for data and commands. It does this through a variety of interrupt-driven DMA (direct memory access) and polled signals. A simplified diagram of the primary processes related to the gyro and accelerometer signal-processing is shown in Figure 12-1.

12.1 Signal-Processing Diagram and Key

Table 12-1 describes some of the symbols used in the diagram.

Table 12-1: Signal-Processing Symbols

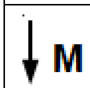
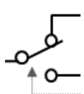
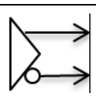
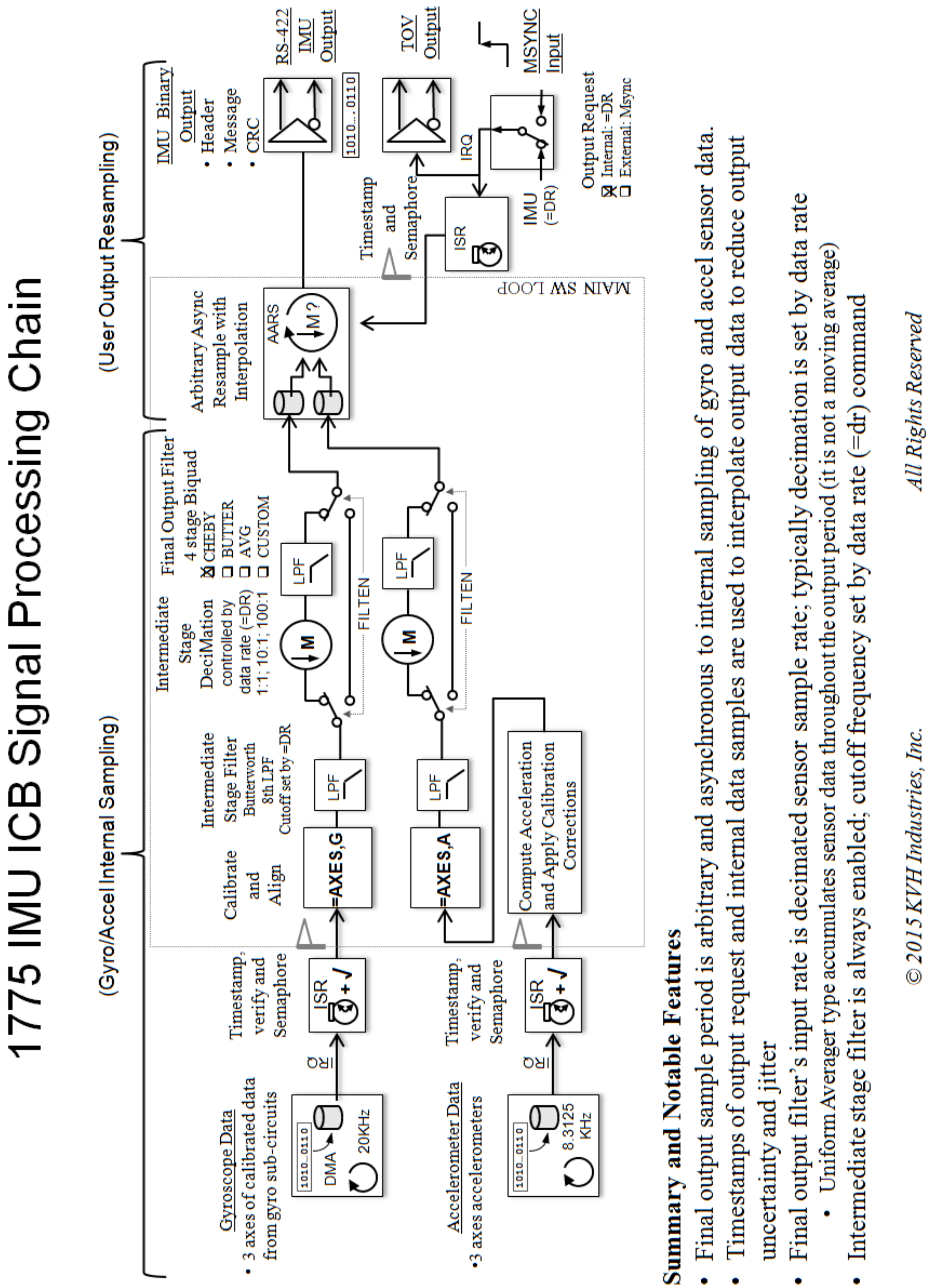
Symbol	Description
	Data container; memory storage of data together with meta-data such as timestamps
	Indicates a timestamp process. The ICB uses an internal clock with better than 20ns resolution to track relative times of various events
	Indicates a low-pass filter process
	Indicates the downsampling portion of sample rate reduction by a factor of M; (M is an industry standard operator symbol for deciMation)
	Indicates a switchable data path;, possibly a virtual switch as in a software path rather than a physical switch
	Indicates a differential signal output
1010….0110	Indicates serial data stream
	Indicates a semaphore flag for inter-process communications

Figure 12-1: ICB Signal-Processing Diagram



12.2 Description of Processing Diagram

12.2.1 Sample Data from Sensor Sub-systems

The gyro and accelerometer sub-systems supply data to the ICB at different rates, but the data processing is similar. In the diagram above, the gyro data from three axes (X, Y, and Z) is being processed by a sub-system and sent to the ICB internally at 20 KHz. The sub-system process details are not shown, but do include rotation rate calculation and processing at much higher rates than 20 KHz. After processing and calibration by the sub-system, it is driven to the ICB for preparation for output. The accelerometer data from three axes (X, Y, and Z) is sampled at 8.3125 KHz and sent to the ICB for further processing. Both of these are shown on the left side of Figure 12-1 as serial bit streams from the gyro and accelerometer sub-systems flowing into data containers at their sample rates. As this data is updated in the ICB, an interrupt-driven process will verify the data, add a timestamp, and then notify other software processes with semaphore flags.

In the case of the gyro data, the values have already been calibrated for bias, scale factor, and linearity versus temperature by the gyro sub-system. The ICB applies any user- configured change in axes rotation and any other calibration factors (not shown) as needed. For the accelerometer data, the ICB performs the temperature calibration needed and then applies user axes rotation.

12.2.2 Intermediate Stage Processing

Because the final output sample rate to the user is much slower than the internal input sample rates from the sub-systems, data for gyros and accelerometers must be downsampled internally. The associated anti-alias filtering is automatically adjusted based on the ratios of the *expected* output rate to the internal rates. Note the term "*expected,*" since for external MSYNC-controlled output, the actual output rate is not known. However, for internally timed output, the data rate is configured by command and the output rate is known.

Decimation, filtering followed by downsampling, in the ICB has an intermediate stage and a final stage. The final stage can be disabled by command (=FILTEN,0) and it can be configured by command (=FILTTYPE) to be either a pre-defined or semi-custom Chebyshev or Butterworth type, a custom filter, or to use as a Uniform Averager function. The intermediate stage filter is always enabled, but its low-pass filter cutoff frequency and downsampling rate, shown in the diagram as ↓M, are determined by the set data rate.

The intermediate filter stage is run at the ICB input data rate. That is, for each data sample accepted from the gyro or accelerometer sub-system, the data is put into its intermediate stage filter function. This generates a filter output as well. The intermediate filter runs a biquad filter function that is always configured to use the Butterworth type (8^{th} order) coefficients, independent of output filter configuration, to implement the low-pass filter prior to downsampling at either a 1:1, 10:1, or 100:1 ratio. The output of the intermediate filter/downsampler is synchronous to the input and this is, therefore, an integer downsample of the input data. The downsampling ratio is controlled by data rate and the output filter selection. Intermediate filter cutoff is set by the data rate in very coarse steps to prevent aliasing the downsampled data. The intermediate filtering and downsampling used at various data rates is shown in Table 12-2.

Table 12-2: Filtering and Downsampling

Output Data Rate (=DR) (Hz)	Gyro Internal Sample Rate (Hz)	Gyro Filter Cutoff Frequency (Hz)	accelerometer Internal Sample Rate (Hz)	accelerometer Filter Cutoff Frequency (Hz)	Decimation Downsample Ratio (if used)
>= 100	20000	10000	8312.5	4156.25	1:1
>= 10 to < 100	2000	1000	831.25	415.625	10:1
< 10	200	100	83.125	41.56	100:1

12.2.3 Processing With Final Output Filter Disabled

As shown in the Signal-Processing Diagram, the FILTEN configuration determines the data path that selects whether the intermediate stage downsampler and the final output filters are used. Even when a user disables the filtering with the =FILTEN,0 command, the data is passed through the intermediate stage filtering portion of the decimator, but not the downsampler. When the final output filter is disabled, the output of the intermediate stage filter is made available to the final output stage for arbitrary resampling and interpolation. This is shown in the diagram as being stored into the output data containers.

12.2.4 Processing With Final Output Filter Enabled

When the final stage filtering is enabled, the intermediate downsampling process is done and the data is passed into the user-configured final output filter. The filter output is then stored with the timestamps into the output data containers. Since the internal sampling rates of the gyros and accelerometers are different, they require different final stage filter coefficients, even though they share the same final output rate.

12.2.4.1 Final Output Filter As Chebyshev/Butterworth/custom

The final output filters must be designed using the internal sampling rates defined in the table shown in Table 12-2. The final stage filter input rate (i.e., its sampling rate) is the output of the intermediate stage decimation. For the Chebyshev, Butterworth, and user-customized filters, the final stage filtering is done with a 4-stage cascaded biquad process. This allows up to an 8^{th} order filter. The diagram shows this as low-pass filtering and this is the typical type of filtering used to convert from the higher internal sample rates to the lower output rate. However, for a custom filter, the user can define the filter coefficients as desired to implement a pure low-pass filter or a combination of low-pass, band-pass, and/or band-reject filtering.

12.2.4.2 Use with the Uniform Averager Type Filter

The Uniform Averager type is a special filter case and does not use the biquad filter stages. When selected, data is still passed through the intermediate decimator (filter and downsampler) and then into the Uniform Averager's accumulation process. This accumulation process uses two accumulators: one for the newest downsampled gyro/accelerometer data and one for one sample back in time. There is also a data counter, so it can later compute the average when final output is needed. The final accumulated data is later interpolated and then finally averaged just prior to when the output data is packaged. The Uniform Averager type filter is thus computing the average of the samples over the output period and is not a simple moving average. This filter type is automatically configured if the user selects the external MSYNC type of output data request, but can be subsequently overridden to use the biquad stages for filtering.

12.2.5 Final Output Data Request

Depending on the configuration, the output of data is triggered from either the MSYNC input or a divided clock generated by the unit. This is shown in the diagram as an Output Request selection check box below a selection switch. The data output request will be converted to the TOV signal output and will trigger the ICB to take a timestamp and signal the process needed to generate the output according to one of the configured data formats. If the ICB does not see an output request within 2 secs (1/2 Hz), the ICB will output data on its own, essentially acting like a watchdog timer. The ICB does not change any filtering to limit aliasing in this case. One benefit of this is that during testing or development with the IMU, it can be a useful indication that the unit is working, but perhaps not receiving an external MSYNC. However, the 1/2 Hz output is not intended to be used as a normal means of obtaining data.

When the ICB's main software loop process sees the request for data output, it will "freeze" the output data containers by making a copy. This is shown as "AARS" or arbitrary asynchronous resampling. The original containers can then continue to be updated while the frozen values can be prepared for output. These containers hold the gyro or accelerometer data for each channel and the timestamps associated with when they were received from the sub-systems. They also contain a similar set of data/timestamps for the prior sample set (i.e., one internal decimated time period old). The difference in time between the new and older samples would thus depend on the configured data rate and the output filter configuration.

The filtered data old/new pair is then operated on by an interpolation function to compute an output value based on a linear interpolation model of the new and old values and the delta time between the internal samples and the output sample request. This is described in detail in a subsequent section.

The interpolated value is then further processed to do some of the following:

- If Uniform Averager is active, then the interpolated value is divided by the number of internal samples it contains.
- Any limits to rate (or acceleration) are checked and enforced and the validity status is updated as needed. This is required by the calibration range. Unit conversion is applied as configured. This changes rate (or acceleration) to delta-angle (or delta-velocity) and also the configured rotation units (radians or degrees) or linear units (meters or feet).

The output process then goes on to combine the various data as needed by the output format into the final output message. This would include the appropriate header word, status values, temperatures, CRC word, etc.

12.2.6 Additional Information: Output Rate Resampling

In the 1775 IMU family, the rate of the output of data to the user is configurable in a number of ways. It is, however, asynchronous to the internal sampling rate of both the gyro and the accelerometer sub-systems and it occurs at a lower data rate. Therefore, there is a need to do the following:

1) resample the internal discrete data points at a slower and arbitrary rate
2) limit latency to preserve real-time response used for stabilization applications

Ideally, sample rate conversion should be done at integer multiples, up or down, of the input sampling rate. Then some simple integer interpolation-upsampling and/or decimation-downsampling can achieve the sample rate conversion. If the output to input rates can be related by ratios of integers, then both interpolation-upsampling followed by decimation-downsampling can be applied.

Generally, in a system where the input and output rates are not direct integer multiples or integer-ratio related (i.e., they are asynchronous and, by some definitions, arbitrary) there are some non-realtime or near-realtime algorithms that can be used. For systems that can tolerate some latency (e.g., music sampling conversion or imaging), these include use of processing buffers to achieve low sample jitter rates, highly complex FIR filtering to minimize phase distortion and other techniques that are compatible with non- or near-real-time systems.

Some Optional References About Asynchronous Resampling Include:

1) http://www.iet.ntnu.no/courses/fe8114/slides/upsanddownsofasrc.pdf
2) http://www.analog.com/media/en/technical-documentation/technical-articles/5148255032673409856AES2005_ASRC.pdf

When there is a need to provide on-demand, real-time output with minimal data latency, there are limits to using some of these techniques, which forces some compromises. For example, we use cascaded biquad (IIR) stages rather than wide FIR filtering to simplify processing burden and achieve steep anti-alias roll-off, but this sacrifices phase shifting resulting in frequency-specific distortion that an application might not tolerate.

When we use the term “arbitrary” in “arbitrary sample rate conversion,” we mean that the output sample rate may be different (asynchronous) from the input sample rate and possibly non-uniform in time (non-isochronous) with respect to itself. Specifically, in our system the output can be configured to a repeatable rate (isochronous) driven by an internal timer or on-demand (arbitrary and non-repeatable) driven by the user-interface. Where our output rate is isochronous, it is not an integer multiple or ratio of the internal data sampling rates of sub-systems. In fact, internally the sample rates of each gyro and each accelerometer are separate and unique. Therefore, we cannot simply provide integer downsampled data as an output.

If the output sampling rate is much less than the input sampling rate (i.e., it is a highly oversampled system) then it may be sufficient to simply apply a low-pass filter to the input samples and resample at some other discrete times and accept the added slight jitter.

In the IMU, the user-interface output rates are lower than the internal sampling (input) rates, but can be in the same order of magnitude, so conversion requires use of some multi-rate asynchronous arbitrary downsampling. To reduce jitter and uncertainty in the sample rate conversion, the output value is interpolated using timestamps.

12.2.7 Output Data Interpolation

Arbitrary sample rate conversion involves computing the output sample values based on the input sample values and the timing relationships of the output to the input. Therefore, by nature, it is an interpolation process.

One way to think of this would be to interpolate by conversion of the input samples from discrete/digitized values back to the continuous/analog domain and then filtering and re-digitizing at the new output rate. This would be analog interpolation. We can also use purely discrete time algorithms to interpolate the input samples to generate new output data values by constructing a model of the behavior of the signal based on nearby samples. The IMU uses simple linear interpolation whereby a percentage of the prior sample mixed with a complementary percentage of the latest sample is used for the output. Thus, the interpolation model used between the samples is a straight line.

For the 1750 IMU and 1775 IMU, the interpolation algorithm uses the last two internal data points along with their timestamp information to derive the output value. While this adds a single internal sample rate period of latency, it provides a more accurate output value, with less jitter and uncertainty than a simple sample-and-hold output based on the most recently available internal data. A better description of the operation of the interpolation algorithm follows.

In the timing diagrams below, the *Intermediate Data Available* timing represented by the higher speed internal sampling rates as data (D1, D2, D3, etc.) is updated internally. The *Output Request* represents the signal to the system that output of data to the user is requested. This may either be from an internal clocked signal or the external MSYNC signal.

```
                    _____ _________________________ ____________________
Intermediate        ____X__________D1______________X________D2__________
Data Available          |                          |
                        |<-------- T1 -------->|<-- T2 -->|
                                                          |_____
Output Request      ______________________________________|      |____
```

As seen in the diagram above, the output request is asking for data at time T2 after sample D2 becomes available, since its leading edge occurs after D2. However, no data is available for that point in time yet since D2 is the latest data available. Therefore, the system instead makes a translation in time to output data associated with the time T2 after D1 (one internal sample prior). This is followed by linear interpolation between the D1 and D2 data to derive a value between them. The timing diagram below shows how the system interprets the output request signal.

```
                    _____ _________________________ ____________________
Intermediate        ____X__________D1______________X________D2__________
Data Available          |                          |
                        |<-------- T1 -------->|
                        |<-- T2 -->|
                                   |____
Output Request      _______________|     |__________________________
```

If time T2 is nearly 0, then even though the D2 values would be available, we would output virtually nothing of them and instead output data primarily based on the D1 values. As time T2 increases, we would output more and more of D2 and less of D1. We would thus maintain the output of data at one internal sample period delay.

The alternatives to this would be to simply output the newest data available or, possibly to attempt prediction of the output based on the past history. In the first case, we would end up with an output timing variation of zero to as much as one internal data sample period as the time T2 varied from 0 to T1. The use of interpolation mitigates this output uncertainty (jitter). In the second, predictive case, there is less latency and justification to do this might be if the error can be bounded by the filtering used and how far out in time the prediction is made. However, the result is technically non-causal, since we cannot be certain of the value at a time in the future.

The intermediate sampling period latency associated with interpolation mentioned above will depend on the system configuration.

- If the system's final output filter is disabled, then the intermediate sample period is based on the internal highest data rate sample timing (20 KHz for 1775 IMU gyros, 8.3125 KHz for accelerometers).
- If the system output filter is enabled (e.g., Uniform Averager, Chebyshev, Butterworth, or custom) the intermediate output rate (i.e., final stage input sample rate) is determined by the data rate configured. Therefore, the relative latencies will change as well. Note: the Averager filter type is still subject to the downsampled time period associated with the data rate configuration. In the case when using the Averager with the external MSYNC mode, it may be useful to set the data rate to 100 Hz or above, so the internal intermediate downsampling is set to 1:1 and the intermediate filtering is minimized. The Averager can then operate at full speed.

Based on the interpolation scheme, data is output according to the following formula:

D_out = D1 * (1 - T2 / T1) + D2 * (T2 / T1)
where D1 is the prior internal data value and D2 is the most recent internal data value

As T2 shrinks toward 0, this results in more of the interpolated value being a result of D1 and less of it being D2. Similarly, as T2 approaches T1, it uses more of D2 and less of D1. This results in a linear interpolated value, with the compromise of adding one data cycle of latency. The data cycle here would be based on the internal time tags of the D1 and D2 points.

Optimization of the calculation of the equation above is as follows:

D_out = D1 * (1 - T2 / T1) + D2 * (T2 / T1)
= D1 * ((T1 - T2) / T1) + D2 * (T2 / T1)
= (1 / T1) * (D1 * (T1 - T2) + D2 * T2)
= (1 / T1) * (D1 * T1 - D1 * T2 + D2 * T2)
= (1 / T1) * (D1 * T1 + (D2 - D1) * T2)
= D1 + (T2 / T1) * (D2 - D1)

Based on the final equation, we see this is simply the equation of a line in the equation below:

Y = mx + b; where:
- m = (D2 - D1) / T1
- x = T2
- b = D1

12.2.8 Biquad Filtering (Additional Information)

A biquad filter stage is simply a two-pole infinite impulse response (IIR) filter, where both the numerator and denominator are quadratic equations. The numerator coefficients, typically b_n, define the feedforward values. The denominator coefficients, typically a_n, define the feedback coefficients. Based on the selection of coefficients, it can behave as an FIR filter when no feedback is used. Below are some basic references about biquad filtering.

- https://en.wikipedia.org/wiki/Digital_biquad_filter – this is a good explanation of the basics of biquad operation along with some useful references
- http://www.earlevel.com/main/2003/02/28/biquads/ – note their usage of a_n and b_n coefficients is swapped from our nomenclature; there is no industry standard for this. This site has some basic calculators to compute coefficients, but only for single stage (non-cascaded) biquads.
- http://www.ti.com/lit/an/slaa447/slaa447.pdf – some basic biquad information and some other information more targeted at the TI DSP chip. Appendices have some Matlab scripts for single stage biquad determination.

There is not an industry-standardized nomenclature for coefficient designation as a_n or b_n and some literature will swap them. In addition, some literature will show the feedback equations in the denominator as additions, the negative feedback being in the coefficients themselves. Alternatively, some will show the feedback equations as subtractions and assume positive coefficients. At the user configuration level, the 1775 IMU implements feedback addition, so the a_n coefficients should incorporate the appropriate negative signs.

In the 1775 IMU, the filter calculations are done with SPFP values (32-bit) so they are somewhat less sensitive to quantization and overflow than if they were fixed-point. However, it is a good idea, though not strictly necessary, when cascading stages to order them in increasing order of Q and/or gain to improve stability. This is particularly true if any stages result in significant gain peaking near the cutoff point; those stages should be implemented later in the cascade, so the prior stages can reduce the signal energy subjected to the peaking. This is typically required when using fixed point calculations. There are a number of alternatives for computation of custom filter coefficients, including software from some, sources such as those below (listed in order of decreasing cost):

- Matlab with DSP toolboxes: http://www.mathworks.com/products/matlab/
- Mathcad with DSP toolboxes: http://www.ptc.com/engineering-math-software/mathcad
- Iowegian: https://iowegian.com/scopeiir
- Iowa Hills: http://iowahills.com/4IIRFilterPage.html

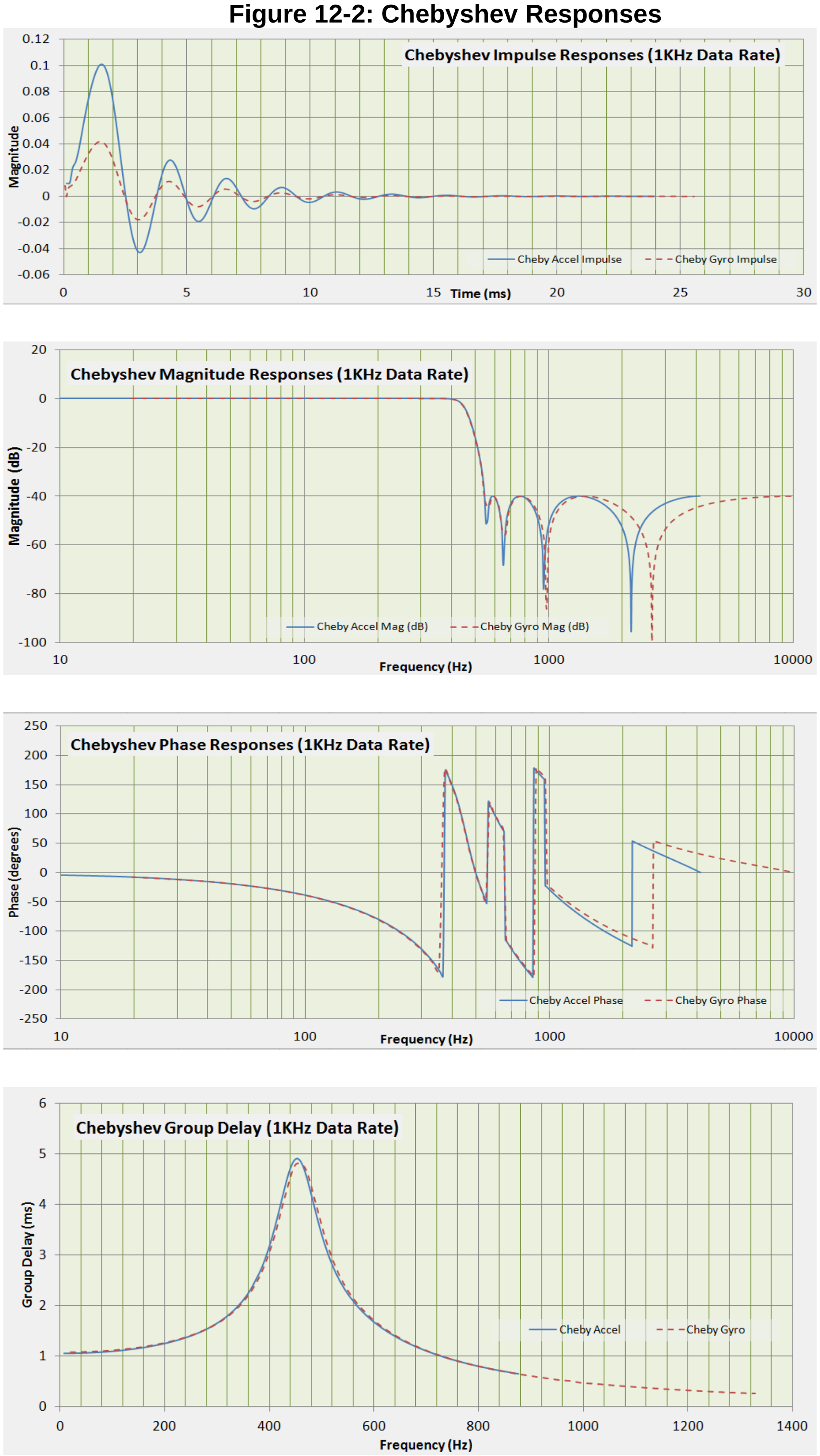
KVH makes no specific endorsements or recommendations and has not fully tested the above for compliance with the 1775 IMU. When designing filters, we recommend testing the behavior using the IMU's "=TESTFILT" command to extract the impulse response. The behavior inside the IMU can then be verified against theoretical performance for stability, frequency response, and to ensure that there are no unexpected issues (for example, due to coefficient quantization or coefficient entry errors).

12.3 Default Final Output Filter Responses

12.3.1 Chebyshev

Figure 12-2 shows the plotted impulse, magnitude, phase responses and group delays of the default Chebyshev (type II) filter at a 1000 Hz data rate; =FILTTYPE,<A|G>,CHEBY,8,0.01,545 N= 8th order, GSTOP = 0.01 (-40dB) FSTOP = 545 Hz

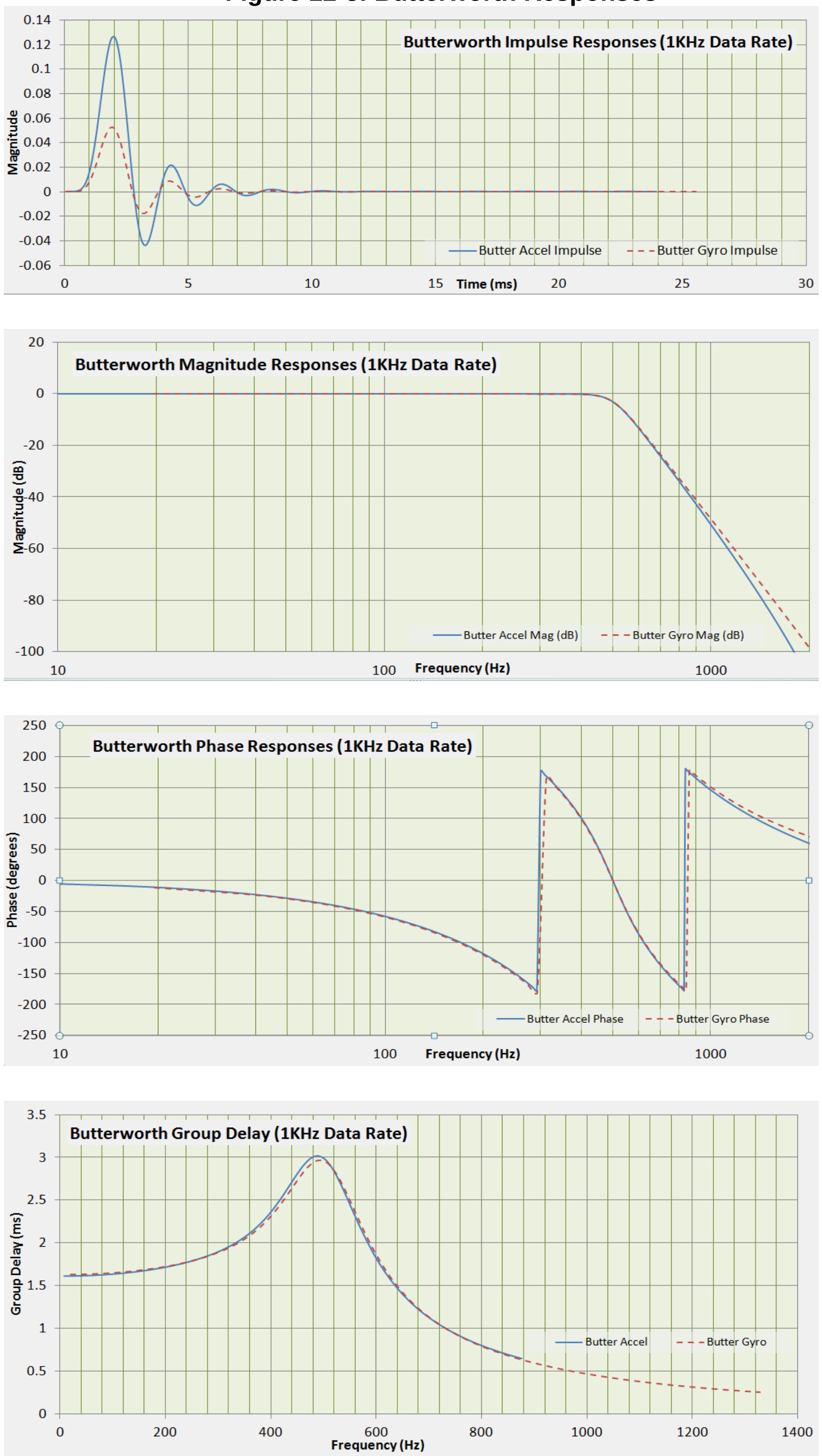
Figure 12-2: Chebyshev Responses



12.3.2 Butterworth

Figure 12-3 shows the plotted impulse, magnitude, phase responses, and group delays of the built-in Butterworth filter at a 1000 Hz data rate. =FILTTYPE,<A|G>,BUTTER,8,500 8th order, FCUTOFF = 500 Hz

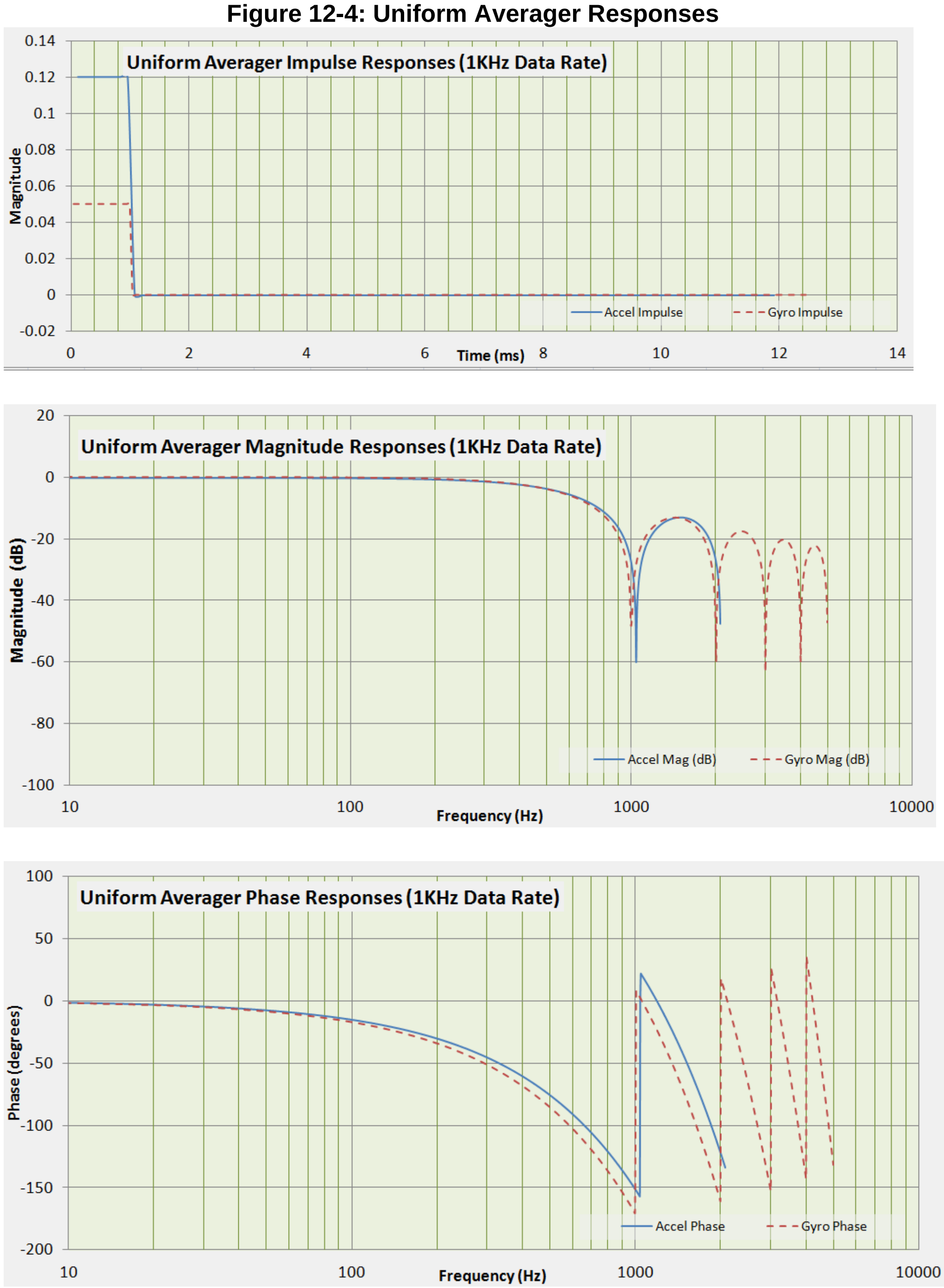
Figure 12-3: Butterworth Responses



12.3.3 Uniform Averager

Figure 12-4 shows the plotted impulse, magnitude and phase of the built-in Uniform Averager filter at a 1000 Hz data rate; =FILTTYPE,<A|G>,AVE. For gyros, this represents a 20:1 sample reduction and for accelerometers, it is an 8.3125:1 reduction. The group delay of the Uniform Averager is a constant and is computed as 0.5/FOUT, where FOUT is the frequency of the final output; for 1000 Hz output rate the delay is 0.5ms.

Figure 12-4: Uniform Averager Responses



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